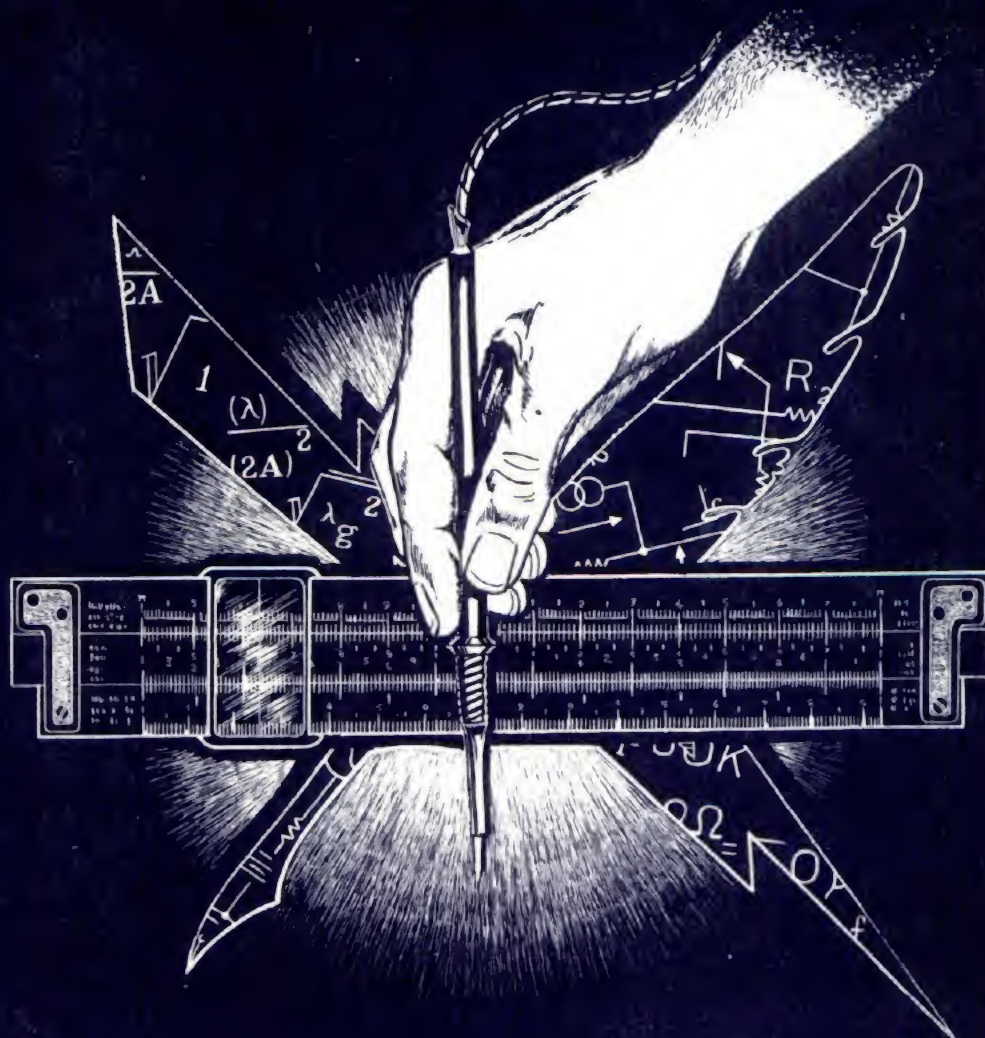

COMMUNICATION TECHNICIAN M 3 & 2

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE NAVPERS 10232-A

PREFACE

This book has been written to aid enlisted personnel of the United States Navy and Naval Reserve in preparing for advancement to the rates of Communications Technician, Maintenance Branch, 3 and 2.

The subjects with which the striker must be familiar and the skills he must acquire before he can qualify for advancement to Communications Technician, Maintenance Branch, 3 and 2 are outlined officially in the Manual of Qualifications for Advancement in Rating for Communications Technicians, Naval Security Group Headquarters Instruction. P002573.5 series. Before beginning to study for the rating, the striker should check the currently effective edition of the instruction.

This test contains information concerning the theory and operation of the various kinds of general and specialized electronic and electromechanical equipment used in the Naval Security Group, including radio and other electronic communication and special equipment, antennas, direction finding equipment, and teletypewriters. Those who work in communications are aware how fast procedures and equipment evolve. This book was up to date when published, and it will, from time to time, be revised. Between revisions some obsolescence is unavoidable. For this reason it is suggested that the student with access to official communications publications and manufacturer's equipment manuals use them as much as possible for his study.

As one of the Naval Security Group Training Courses, Communications Technician, Maintenance Branch, 3 & 2 was prepared by the U. S. Naval Security Group Headquarters Activity in cooperation with the Bureau of Naval Personnel.

Original Edition 1961

Revised 1965

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CONTENTS

CONTENTS (Continued)

CREDITS

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READING LIST

NAVY TRAINING COURSES

Basic Electricity, NavPers 10086-A
Basic Electronics, NavPers 10087-A
Mathematics, Vol. 1, NavPers 10069-B
Basic Handtools, NavPers 10085-A

OTHER PUBLICATIONS

Department of the Navy Security Manual for Classified Information, (Ch. 1-7), OPNAVINST 5510.1B
Communications Instructions, Security, ACP 122B
U. S. Naval Communication Instructions (Ch. 5), DNC 5C
An Introduction to CT Rating, NSGTP 86401
BuShips Technical Manual, (Ch. 9670), NavShips 250-000
Electronics Information Bulletin, NavShips 900,022A

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Educational Services Officer.* Current issues of the following courses are recommended:

Number	Title	Number	Title
C 150	Review Arithmetic	D 291	Physics II
C 151	General Mathematics I	C 781	Fundamentals of Electricity
C 152	General Mathematics II	C 858	The Slide Rule
D 164	Beginning Algebra I	C 885	Fundamentals of Radio
D 165	Beginning Algebra II	B 890	Radio Servicing and Repair I
D 166	Advanced Algebra	B 891	Radio Servicing and Repair II
D 290	Physics I		

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified on the active duty orders."

CHAPTER 1

THE COMMUNICATIONS TECHNICIAN, M BRANCH

This training course is designed to help you meet the professional qualifications for advancement to Communications Technician M Branch, 3 and 2. The qualifications which were used as a guide in the preparation of this training course are those set forth in the Manual of Qualifications for Advancement in Rating for Communications Technicians, Naval Security Group Instruction P002573.5B. Changes in the qualifications subsequent to the Bravo edition are not reflected in the information contained in this publication.

Following this introductory chapter, information is included concerning certain phases of M Branch work. However, since this training course is limited to the Unclassified level, information pertaining to the more sensitive aspects of the M Branch must be obtained from appropriate publications listed in the effective edition of Training Publications for Communications Technician Examinations, Naval Security Group Instruction 002573.3.

The remainder of this chapter is concerned with the enlisted rating structure, the Communications Technician rating, requirements and procedures for advancement in rating, and references that will help you not only in working for advancement but also in performing your duties. Information is also given on how to make the best use of Navy Training Courses. Therefore, it is strongly recommended that you carefully study this first chapter before proceeding with an intensive study of the other chapters of this training course.

THE ENLISTED RATING STRUCTURE

The present enlisted rating structure, established in 1957, includes three types of ratings—general ratings, service ratings, and emergency ratings.

GENERAL RATINGS identify broad occupational fields of related duties and functions. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

SERVICE RATINGS identify subdivisions or specialties within a general rating. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

EMERGENCY RATINGS generally identify civilian occupational fields. Emergency ratings do not need to be identified as ratings in the peacetime Navy, but their identification is required in time of war.

THE COMMUNICATIONS TECHNICIAN RATING

Before and during World War II, the jobs now performed by Communications Technicians were done by men selected from several other ratings such as Radioman, Yeoman, Electronic Technician, and others. That group of personnel from the various ratings gradually was organized into one unit which is now called the Naval Security Group (NAVSECGRU). Realizing that the work done by those persons assigned to the NAVSECGRU required special skills and training which were not available to each of the ratings then being utilized, the Navy established, in April 1948, the Communications Technician (CT) rating. CTs, together with specially designated officers and warrant officers, comprise the NAVSECGRU.

As the NAVSECGRU expanded and became responsible for a wide variety of technical programs, the need for specialization—even within the CT rating—became apparent. Consequently, six separate branches have evolved within the CT rating: the R or Collection Branch, the O or Communications Branch, the A or Administrative Branch, the M or Maintenance Branch, the T or Technical Branch, and the I or Interpretive Branch.

The CT rating is a general rating as defined in the foregoing section describing the enlisted rating structure; there are no service or emergency ratings within the CT rating. Separate professional qualifications for each of the six branches within the CT rating have been established. Although you are a part of the general CT rating, you will be examined for advancement on knowledge and skills applicable to the M Branch. Of course, you will also be expected to be proficient in subjects, such as security and organization of the Naval Security Group, which are of equal importance to all CT branches.

THE CT M BRANCH

As a CT M 3 or 2 you will develop skills involved in installing and maintaining complex electronic equipment associated with all types of electromagnetic transmissions. You will also learn to perform such accounting and administrative functions as are necessary to carry out duties in the field of radio communications.

M Branch duty tours are varied and interesting. CT M personnel may expect to utilize their special skills on board Navy ships, in aircraft, and at shore bases located throughout the world. Wherever you work, you will learn that other Navy personnel will be relying on the accuracy and efficiency of your work. Attention to small details is of utmost importance because the results of your work will be used at all levels of government. One small omission or careless error might start a chain of events which could, in addition to costing large sums of money, actually jeopardize the security of the nation.

LEADERSHIP

Many books about leadership have been published and more appear each year. Usually they present excellent definitions of complex characteristics such as honor, initiative, and personal behavior. Most of them give interesting examples of the great leaders of the past and how those famous men applied those principles to themselves. Sometimes it seems difficult to relate all of that valuable information to ourselves personally.

As a petty officer, leadership certainly will concern you. As you advance in the CT rating, you will be placed in charge of more men and larger tasks. If you possess leadership ability you will find respect, efficiency, and a fine working atmosphere wherever you go. If you have failed to train yourself in basic leadership principles, you will find only disappointment and perhaps even ridicule. Do yourself a most important favor at the start of your Navy career and begin to practice leadership now while you are still relatively free of the burdens of higher responsibility. You might one day be very much embarrassed to discover that leadership ability is not mysteriously acquired each time you sew on a new rating badge. Like any other skill, leadership must be studied and practiced. Following are a few basic guidelines for you to follow; whether or not you do so will probably determine your being a success in life or simply another "also-ran."

MILITARY ABILITY

No matter what a petty officer's technical specialty may be, he must understand and carry out his military duties. He must be able to take charge of a group of men and show and tell them how a job should be done. A petty officer should know what to do and how to do it when faced with matters of first aid, hygiene, damage control, fire prevention, and nuclear, biological, and chemical warfare. In short, he must accomplish his military duties and take care of his men. A petty officer's working relationship with others is of great importance to the success of his work and the mission of his activity. In your day-to-day working relationships, you will be required to cooperate with others. This is true not only within your own division but also with men in other divisions. Being able to get along is, at times, just as necessary as proficiency in performing your technical skills. The ability to get along with others is within itself a definite skill which can be developed in much the same manner as a technical skill.

PROFESSIONAL KNOWLEDGE

As a petty officer you should know your job at least as well as any of those persons working for you, and, if possible, better. Learn as much as you can about the operation of each piece of equipment in your working area. Be able to give honest instructions to your men about all phases of your work. To accomplish this you will probably have to seek answers and guidance from your seniors and will have

to read manuals, instructions, and other material related to your work. You will be surprised how much your seniors will respect and appreciate your curiosity when you ask questions and show an interest in learning more about your job and more about the over-all operations of your unit. Learn to use all available working aids. Try to know where you can find information on all phases of your job. Keep up with new techniques and equipment. Attempt to learn something new about your job every day. Be realistic and actually ask yourself, "Have I learned anything new today?" If not, you have moved one step backward on that particular day.

PERSONAL BEHAVIOR

Let your men see that you support your seniors just as much as you expect your men to support you. If your men hear you enforce what may be a disagreeable order from higher authority, they will understand the situation and show their respect by supporting your own orders to them. Share your men's problems. Avoid use of profanity and discourage its use among your men. Try to improve your speech and your manner of speaking directly to people. Be moderate in your personal habits. Readily admit you are in error when you make a mistake and do not try to bluff your way through a discussion. Bear in mind a most important rule of thumb in the skill of leadership: "Praise in public but reprimand in private."

MORAL BEHAVIOR

Providing moral guidance to your men is also the duty of the petty officer. The special emphasis placed on this phase of leadership is set forth in General Order Number 21, which directs you to observe the high standards of moral behavior and devotion to duty as set forth in Navy Regulations. Thus, you are required to set an example for those under your leadership by scrupulously observing all rules and regulations of the Navy, by indicating initiative and determination in accomplishing your work, by relfecting high moral standards in your behavior, and by ensuring that your men receive your full attention and supervision.

PERSONAL APPEARANCE

It is basic human nature for people to admire the man who is clean, neatly dressed, and carries himself well. Good personal appearance is easy to maintain and is also one of the most readily noted characteristics of the leader. Keep your uniforms as clean and neat as possible and wear them properly. Take a good honest look at yourself now and then, and take measures to improve your personal appearance when possible. Indulge in regular periods of physical exercise. You will not only feel better, but you will also be adding to your qualities as a leader. Develop a ready smile and present a cheerful appearance to your men when the going gets difficult.

ADVANCEMENT IN RATING

Some of the rewards of advancement in rating are easy to see. You receive more pay, your job assignments become more interesting and more challenging, you are regarded with greater respect by officers and enlisted personnel, and you enjoy the satisfaction of getting ahead in your chosen Navy career.

But the advantages of advancing in rating are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By each advancement in rating, you increase your value to the Navy in two ways. First, you become more valuable as a technical specialist in your own rating. Second, you become more valuable as a person who can train others and thus make far-reaching contributions to the entire Navy.

HOW TO QUALIFY FOR ADVANCEMENT

What must you do to qualify for advancement? The requirements may change from time to time, but basically you must:

1. Complete a certain amount of time in your present grade.
2. Complete the required military and professional training courses.
3. Demonstrate your ability to perform all the PRACTICAL requirements for advancement by completing the Record of Practical Factors, NavPers 760.
4. Be recommended by your commanding officer, after the petty officers and officers supervising your work have indicated that they consider you capable of performing the duties of the next higher rate.

5. Demonstrate your KNOWLEDGE by passing a written examination on (a) military requirements and (b) professional qualifications.

Some of these general requirements may be modified in certain ways. Figure 1-1 gives a detailed view of the requirements for advancement of active duty personnel; figure 1-2 gives the information for inactive duty personnel.

Remember that the requirements for advancement can change. Check with your educational services officer to be sure that you know the current requirements.

Advancement in rating is not automatic. After you have met all the requirements, you are ELIGIBLE for advancement. You will actually be advanced in rating only if you meet all the requirements (including scoring high enough on the written examination) and if the quotas for your rating permit your advancement.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement in rating? You must study the qualifications for advancement, work on the practical factors, complete required Navy Training Courses, and study other material that is required for advancement in your rating. To prepare for advancement, you will need to be familiar with the (1) CT Quals Manual, (2) Record of Practical Factors, NavPers 760, (3) List of Training Publications for Communications Technician Examinations, NAVSECGRU INSTRUCTION 002573.3, and (4) applicable Navy Training Courses. The following sections describe these publications and give you some practical suggestions on how to use them in preparing for advancement.

CT Quals Manual

The Manual of Qualifications for Advancement in Rating for Communications Technicians, NAVSECGRU INSTRUCTION P002573.5 (effective edition) states the minimum requirements for advancement to each rate within each branch. The manual is referred to as the CT Quals Manual. The qualifications, often called "quals," are of two general types: (1) professional or technical qualifications and (2) military requirements.

PROFESSIONAL QUALIFICATIONS are technical or professional requirements that are directly related to the work of each branch of the Communications Technician rating.

MILITARY REQUIREMENTS, which apply to all ratings rather than to any one particular rating, are contained in the effective edition of the Manual of Qualifications for Advancement in Rating NavPers 18068-A (with changes). Military requirements for advancement to third class and second class petty officer deal primarily with military conduct, naval organization, military justice, security, watch standing, and other subjects which are required of petty officers in all ratings.

Both the professional qualifications and the military requirements are divided into subject matter groups; each subject matter group is further divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS. Practical factors are things you must be able to DO. Knowledge factors are things you must KNOW in order to perform the duties of your rating.

The professional qualifications for advancement in your rating are printed in the effective edition of the CT Quals Manual. Study these qualifications and the military requirements carefully. The written examinations for advancement in rating will contain questions relating to the practical factors and the knowledge factors of both the professional qualifications and the military requirements. If you are working for advancement to second class petty officer, remember that you will be examined on the qualifications for third class as well as those for second class petty officer.

At the time this training course was prepared, the effective edition of the CT Quals Manual was NAVSECGRUINST P002573.5B. However, the qualifications are changed more frequently than Navy Training Courses are revised. By the time you are studying this training course, some of the quals for your branch may have been changed. You should, therefore, check the effective edition of the CT Quals Manual to be certain that you have the latest information concerning your professional requirements.

Record of Practical Factors

Before you can take an examination for advancement in rating, there must be an entry

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6.	48 mos. as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3, AME 3, HM 3			Class B for AGCA, MUCA, MNCA.	Must be permanent appointment.	
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS	Locally prepared tests.		Navy-wide examinations required for all PO advancements.				Navy-wide, selection board, and physical.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		
	TARS attached to the air program are advanced to fill vacancies and must be approved by CNARESTRA.							

* All advancements require commanding officer's recommendation.
† 2 years obligated service required.

5.1

Figure 1-1.—Active duty advancement requirements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS *		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
	FOR THESE DRILLS PER YEAR								
TOTAL TIME IN GRADE	48	6 mos.	6 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	24	9 mos.	9 mos.	15 mos.	18 mos.	24 mos.	36 mos.	48 mos.	24 mos.
	NON-DRILLING	12 mos.	24 mos.	24 mos.	36 mos.	48 mos.	48 mos.		
DRILLS ATTENDED IN GRADE †	48	18	18	45	54	72	108	144	72
	24	16	16	27	32	42	64	85	32
TOTAL TRAINING DUTY IN GRADE †	48	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	24	14 days	14 days	14 days	14 days	28 days	42 days	56 days	28 days
	NON-DRILLING	None	None	14 days	14 days	28 days	28 days		
PERFORMANCE TESTS				Specified ratings must complete applicable performance tests before taking examination.					
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 760, must be completed for all advancements.							
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.							
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.						Standard EXAM, Selection Board, and Physical.	
AUTHORIZATION		District commandant or CNARESTRA					Bureau of Naval Personnel		

* Recommendation by commanding officer required for all advancements.
† Active duty periods may be substituted for drills and training duty.

5.2

Figure 1-2.—Inactive duty advancement requirements.

in your service record to show that you have qualified in the practical factors for both the military requirements and the professional qualifications. A special form, the Record of Practical Factors, NavPers 760, is used to keep a record of your practical factor qualifications. This form lists all practical factors both military and professional. As you demonstrate your ability to perform each practical factor, be sure that entries are made in the DATE and INITIALS columns by your supervising officer.

When changes are made to the CT Quals Manual, revised forms of NavPers 760 are provided as required. Extra space is allowed on the form for entering additional practical factors which may be added to the CT Quals Manual. The form also provides space for recording demonstrated proficiency in skills which are within the general scope of the rating but which are not identified as minimum qualifications for advancement.

If you are transferred before you qualify in all practical factors, the NavPers 760 form should be forwarded with your service record to your next duty station. You can save yourself a lot of trouble by making sure that this form is inserted in your service record before you are transferred. If the form is not in your service record, you may be required to requalify in the practical factors which have already been checked off.

Study List

The List of Training Publications for Communications Technicians Examinations, NAVSECGRUINST 002573.3 (effective edition), is a very important publication when you are preparing for advancement in rating. This bibliography lists the Navy training courses and other reference material to be used by personnel studying for advancement in rating. Usually referred to simply as the Study List, this instruction is revised and issued periodically; each revision is indicated by a letter following the instruction number. When using the Study List, be sure that you have the most recent edition.

In the Study List, publications are listed by rate level. If you are working for advancement to third class, study the material listed for third class. If you are working for advancement to second class, study the material listed for second class, but remember that you are also responsible for the publications listed for the third class level.

Do not overlook Part I of the Study List, which lists publications pertaining to the military requirements for advancement. Personnel of ALL ratings must complete the mandatory military requirements for the appropriate rate level before they are eligible to take the examinations for advancement in rating. Part II of the Study List is also important because it lists the material which is common to all branches of the CT rating.

All references in the Study List, both recommended and mandatory, should be carefully studied. All references listed may be used as source material for the written examinations at appropriate rate levels. Although the Study List includes the majority of the material upon which examination questions are based, it is not intended to be an absolutely complete listing; other material pertinent to the qualifications may be used as source material for examination questions.

Navy Training Courses

There are two general types of Navy Training Courses. RATING COURSES (such as this one) are prepared for most enlisted ratings. A rating training course gives information that is directly related to the professional qualifications of one or more branches of the CT rating. SUBJECT MATTER COURSES or BASIC COURSES give information that may apply to more than one CT branch or more than one rating.

Navy Training Courses are revised from time to time in order to keep them up to date. The revision of a Navy Training Course is identified by a letter following the NavPers number. You can determine whether any particular copy of a Navy Training Course is the latest edition by checking the NavPers number and its letter suffix in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061. (NavPers 10061 is a catalog, revised semiannually, that lists all current training courses and correspondence courses.) You will find this catalog useful in planning your study program.

The following suggestions may help you to make the best use of this course and other publications when you are preparing for advancement in rating:

1. Study the military requirements and professional qualifications for your rating before

you study the training course. Refer to the quals frequently as you study. Remember, you are studying the training course primarily to meet requirements set forth in the quals.

2. Set up a regular study plan. It will probably be easier for you to stick to a schedule if you plan to study at the same time each day. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.

3. Before you begin to study any part of the training course intensively, become familiar with the entire book. Read the preface and table of contents. Check through the index. Look at the appendixes. Thumb through the book without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

4. Look at the training course in more detail, to see how it is organized. Look at the table of contents again; then chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope content of the book. As you look through the book in this way, ask yourself some questions. What do I need to learn about this? How is this information related to information given in other chapters? How is this information related to the qualifications for advancement in rating?

5. When you have a general idea of what is in the training course and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit—it may be a chapter, a section of a chapter, or a subsection. The amount of material that you can cover at one time will depend on how well you know the subject and the difficulty level of the material.

6. In studying any one unit, write down questions that occur to you. Many people find it helpful to make a written outline as they study; others simply write down the most important ideas.

7. As you study, relate the information in the training course to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own experience.

8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without looking at the training course, write down the main ideas that you have derived from studying a unit. Don't just quote the book. If you can't express the ideas in your own words, the chances are that you have not really mastered the information.

9. Enroll in enlisted correspondence courses associated with your path of advancement. Correspondence courses, based on Navy Training Courses or on other appropriate texts, are designed to broaden your field of knowledge.

10. Think of your future as you study Navy Training Courses. You are working for advancement to third or second class right now, but soon you will be working toward higher rates. Anything extra that you can learn now will help you both now and later.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the professional qualifications of your rating.

Some of the publications described in this course are subject to change or revision from time to time, some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying cancelled or obsolete information will not help you to do your work or to advance in rating; it is likely to be a waste of time, and may even be seriously misleading.

Electronics and mathematics are fields in which there seems to be no lack of general reference material. The main problem is that of selecting the type of material suited to the needs of a particular job.

Reference material includes texts, handbooks, bulletins, instruction books, and technical maintenance publications. Of course the most useful reference materials are those that contain the desired information in the most readily usable and understandable form. Throughout this training course reference usually is made to publications by their basic

number. You will, in each instance, obtain and use the currently effective or latest edition of the basic publication.

TEXTS

There are several texts that you as a CT M will find helpful: Basic Electricity, NavPers 10086-A; Basic Electronics, NavPers 10087; Basic Handtools, NavPers 10085-A; Mathematics, Volume I, NavPers 10069-B; and Mathematics, Volume 2, NavPers 10071-A.

HANDBOOKS

Handbooks serve a very useful purpose in that they present information about a particular field of work, or about a particular form that can be used by the technician in his everyday work. One such publication is the Handbook of Test Methods and Practices, NavShips 91828; (in the future, this publication will be redesignated NavShips 900,000.103), others are the Handbook of Naval Shore Station Electronics Criteria, NavShips 92675, and the Electronic Test Equipment Handbook, NavShips 900,155.

BULLETINS

One bulletin of great importance to the CT M is the Electronics Information Bulletin (EIB), NavShips 900,022, published biweekly for naval electronics activities. A complete file of these bulletins should be maintained at each NAVSECGRU activity. This bulletin lists field changes and changes that must be entered in instruction books and other publications that are used in the maintenance of electronic equipment. It lists new electronics publications as they become available and gives valuable suggestions for servicing electronic equipment.

Another bulletin of importance is the Shore Supplement to the EIB, NavShips 900,022, published quarterly for naval electronics activities. Articles in this publication are concerned with such subjects as maintenance, installation, field change improvement programs, logistics, budgets, research and development programs, policy directives, and future plans. Information is provided concerning specialized equipments in use at shore activities, shore equipments and systems which have been approved for service use, and test equipment.

A second supplement to the EIB is the Confidential Electronics Information Bulletin (CEIB), NavShips 900,022, published quarterly for naval electronics activities. Articles in this publication are concerned with installation, maintenance, and repair of electronic and electromechanical on-line and off-line security equipment. It is especially important that the CEIB be ready by cryptographic repair facility (CRF) personnel and CT M Branch personnel who are trained and authorized to repair cryptographic equipment.

Although not called a bulletin as such, the Electronics Installation and Maintenance Book (EIMB), NavShips 900,000 includes essentially the same information that was formerly contained in three separate maintenance bulletins. For convenience, the EIMB is comprised of several volumes, covering general information of an electronics nature in each major electronics field.

INSTRUCTION BOOKS

Instruction books very likely will be the type of publication with which you will become most familiar as a CT M. Two copies of an instruction book are normally supplied by the manufacturer with each new piece of equipment. Instruction books are usually divided into several sections or, in a few instances, into several volumes. The first section is a general description of the equipment, its purpose, capabilities, and necessary auxiliary equipment. Generally, the next section treats the theory of operation. This section is extremely important and should not be skimmed over lightly. If you have acquired a basic background in electricity and electronics, the theory section of the instruction book should not cause you much trouble.

Other sections of the instruction book include installation, operation, preventive maintenance, corrective maintenance, and a parts list.

INSTALLATION AND MAINTENANCE MANUALS

A very valuable source of information is the Electronics Installation Practices Manual (EIPM), NavShips 900,171, which provides information on desired or standard methods of making electronic installations. Another good source of information is Shipboard Antenna Details, NavShips 900,121, which consists of

several separately bound chapters. It serves primarily as a source of information for those concerned with installing and maintaining shipboard antennas.

One of the most important and useful manuals available to the CT M is the Bureau of Ships Technical Manual. Two of the chapters of primary interest are Chapter 9004 (formerly Chapter 6), Inspections, Records, Reports and Tests, and Chapter 9670 (formerly Chapter 67), Electronics.

SECURITY

One of your most important tasks as a CT M will be safeguarding the classified information and material entrusted to you. In your daily work you will be handling classified documents, publications, and equipment. It is your personal and individual responsibility to protect the content of all the classified material you handle.

Security is a means, not an end. All the rules and regulations which are spelled out in the many directives and publications on the subject of physical security, communications security, and personal censorship will not guarantee results. You must learn to exercise discretion in carrying out all your duties so that maintenance of security at all times and under all circumstances becomes an automatic and integral part of your work.

In order to carry out your responsibilities, you will need to be familiar with the effective editions of the following publications, consulting them, whenever necessary, on the subject of security:

Communications Instructions, Security, ACP 122B

Navy Regulations, (Chapter 15)

The Department of the Navy Security Manual for Classified Information, OPNAVINST 5510.1 series

CHAPTER 2

ELECTRONICS SAFETY PRECAUTIONS

Nothing in the CT M training program can be more important to the individual CT M than his own personal safety and the safety of his fellow technicians and operators. Because this is such a personal matter, its importance should be obvious. In few other fields of work is the expression, "CARELESSNESS KILLS," more appropriate.

Electronic circuits are potentially dangerous even when the technician uses a great deal of care in his service work. The danger, however, increases in a great proportion as less attention and care is given to safety precautions. It is essential, therefore, that proven, recommended safety precautions be strictly adhered to.

The following example of an accidental electrocution is given to clearly point out a WARNING and a PRECAUTION.

WARNING: When working on live equipment, watch what touches your body as well as what you touch with your hands.

The technician in question was working on a TBM radio transmitter. While he was reaching into the equipment, his body touched a coil having a potential of 2000 volts, carrying over two amperes. His elbow then touched the bulkhead, completing what was for the victim a fatal circuit.

PRECAUTION: Learn artificial respiration. If you know it, it may save your shipmate's life. If he knows it, it may save your life.

In this particular case, another technician present when the victim was electrocuted did not know how to give artificial respiration; and it was not given until a doctor arrived.

ELECTRIC SHOCK

In cases of electric shock, the first thing that must be done is to MAKE SURE THE VICTIM IS NOT TOUCHING A LIVE CIRCUIT. This MUST be done before you touch him. If not sure, use a dry board to push the victim clear of any wires or circuits in the vicinity that may be energized. If a board is not handy, use some other insulating material to push away the wires or circuits that could be "hot." NEVER use a metal bar or conductor of any type to move the man or wires. The object is to remove the victim from the source of shock as quickly as possible without endangering yourself. TWO DEAD MEN WOULD BE TWICE AS BAD AS ONE.

After quickly, but positively, determining that the victim is no longer touching a live circuit, artificial respiration is to be given IMMEDIATELY. For example, power linemen are told to start artificial respiration before lowering the victim from the pole to the ground.

FIRST AID INSTRUCTIONS

Instructions for giving artificial respiration are included in the Standard First Aid Training Course, NavPers 10081-A.

Much material has been written on the subject of safety precautions; and much has been written especially for the benefit of electronics personnel.

All electronics personnel must become thoroughly familiar with United States Navy Safety Precautions, OpNav 34P1, including the latest changes; they should pay special attention to chapter 18. All electronics personnel must likewise become familiar with Chapter 9670 of the Bureau of Ships Technical Manual, NavShips 250,000, including the latest changes; they should pay special attention to section V of chapter 9670.

Additional information that will be of value is contained in Electric Shock, Its Cause and Prevention, NavShips 20-660-42; Chapter 1 of the ELECTRONIC INSTALLATION PRACTICES MANUAL, NavShips 900,171, and in some issues of the Bureau of Ships Journal. Many issues of the EIB also include safety information.

Some of the information contained in the following paragraphs is condensed from the previously mentioned references.

PERSONAL PROTECTION

The technician must not work on electrical (or electronic) equipment when his hands or clothing are wet. He must not wear loose or flapping clothing or clothing with exposed zippers or metal fasteners when working on electronic equipment. The same is true of rings, wrist watches, bracelets, and similar metal items. Another very important item is the matter of shoes. Thin-soled shoes and shoes with metal plates or hobnails must not be worn when work is being done on electronic equipment.

No work must ever be done on live circuits regardless of the magnitude of the voltage except in case of emergency. Under emergency conditions when work must be done on live circuits, every precaution must be taken to prevent accidental grounds. Rubber gloves must be worn and properly insulated tools used; the deck must be covered with an approved insulating material; and at least one other person must be present at all times. All persons must be thoroughly familiar with approved methods of rendering first aid and artificial respiration. Specific instructions pertaining to work on live circuits are contained in Chapter 18 of United States Navy Safety Precautions, OpNav 34P1. (This publication is to be replaced by a manual issued by the Chief of Industrial Relations for shore use and a separate publication issued by the Chief of Naval Operations for the Operating Forces.)

Danger signs and suitable guards must be provided to prevent personnel from coming in accidental contact with high voltages. Danger signs must also be used to warn personnel servicing electronic material against the possible presence of explosive vapors in certain locations and against the POISONOUS EFFECTS OF SMOKE AND STACK GASES.

According to OpNav 34P1, on all circuits where the voltage is in excess of 50 volts, and where the deck or walls are of metallic construction, the worker must be insulated from accidental grounding by the use of approved insulating material. Whenever work of a nature other than electrical is performed in the vicinity of exposed electrical circuits, suitable insulating barriers must be provided to prevent accidental contact with the circuits. Dry wooden stools or platforms are used to prevent the possibility of contact between the workmen's shoes and a wet or damp floor.

Other protective measures include (1) covering metal tool handles with rubber insulating tape; (2) ensuring that fuse boxes are securely closed except when work is being done on them; (3) checking the resistance between the metal bases, frames, and so forth of electronic equipment and ground at regular intervals and after repair work has been done; and (4) being sure that safety devices such as interlocks, overload relays, and fuses are not altered or disconnected except for replacement (no safeguard circuit is to be modified without specific authority).

In connection with insulating metal tool handles with rubber insulating tape, it is also necessary to insulate the shanks of certain screwdrivers (particularly those used inside electronic equipment) with insulating sheaths. Only 3/16 of an inch of the blade need be exposed. Where it is not practicable to tape or otherwise insulate a surface, electricians' insulation varnish may be used.

There are certain special precautions against electric shock that must be taken. Certain pieces of equipment (for example, brushes, dusters, and brooms) not generally considered to be conductive can be dangerous, and the necessary precautions must be taken. Sufficient illumination is very important, and so is keeping one's attention directed to the work being done. Do not trust equipment insulation to protect you from high voltage when work is to be performed, and keep alert to the possibility of accidental grounds or shorts.

In working on live circuits, exercise as much care with low voltages as with high voltages; and never take a shock intentionally from any voltage regardless of how small it may be.

GENERAL ELECTRONICS SAFETY PRECAUTIONS

Because of the constant use of radio at most naval installations the following precautions for radiofrequency circuits should be observed: (1) Energized high voltage output circuits should not be broken except when absolutely necessary and authorized by a qualified officer; and (2) when other transmitting equipment is in use at the same installation or close by, CT Ms

should be on the alert to prevent shock, burns, or other injury to personnel due to energy picked up from adjacent antennas or equipment certain circuits may have to be grounded for safety reasons).

Capacitors are potentially dangerous. Before a CT M touches a capacitor, which is connected to a deenergized circuit (or which is disconnected entirely), he must short circuit the terminals to make sure that the capacitor is completely discharged. A suitably insulated shorting stick should be used for this purpose. A diagram of one type of shorting stick is illustrated in figure 2-1.

The primary function of the shorting stick is to pass the discharge current from a capacitor through the ground wire to ground, NOT through the body of the person discharging the capacitor. The hook enables the technician to fasten the stick to the high voltage terminal which serves as an added protection while work is in progress. It is necessary, of course, to connect the ground clamp to ground BEFORE using the hook.

Some shore stations have provided a shorting stick at each transmitter enclosure. In each case it is so placed that the technician must remove the shorting stick before he can gain access to the equipment.

No person should reach within or enter energized electronic equipment enclosures for the purpose of servicing or adjusting, except when prescribed by official applicable technical manuals and then not without the immediate presence and assistance of another person capable of rendering aid in an emergency.

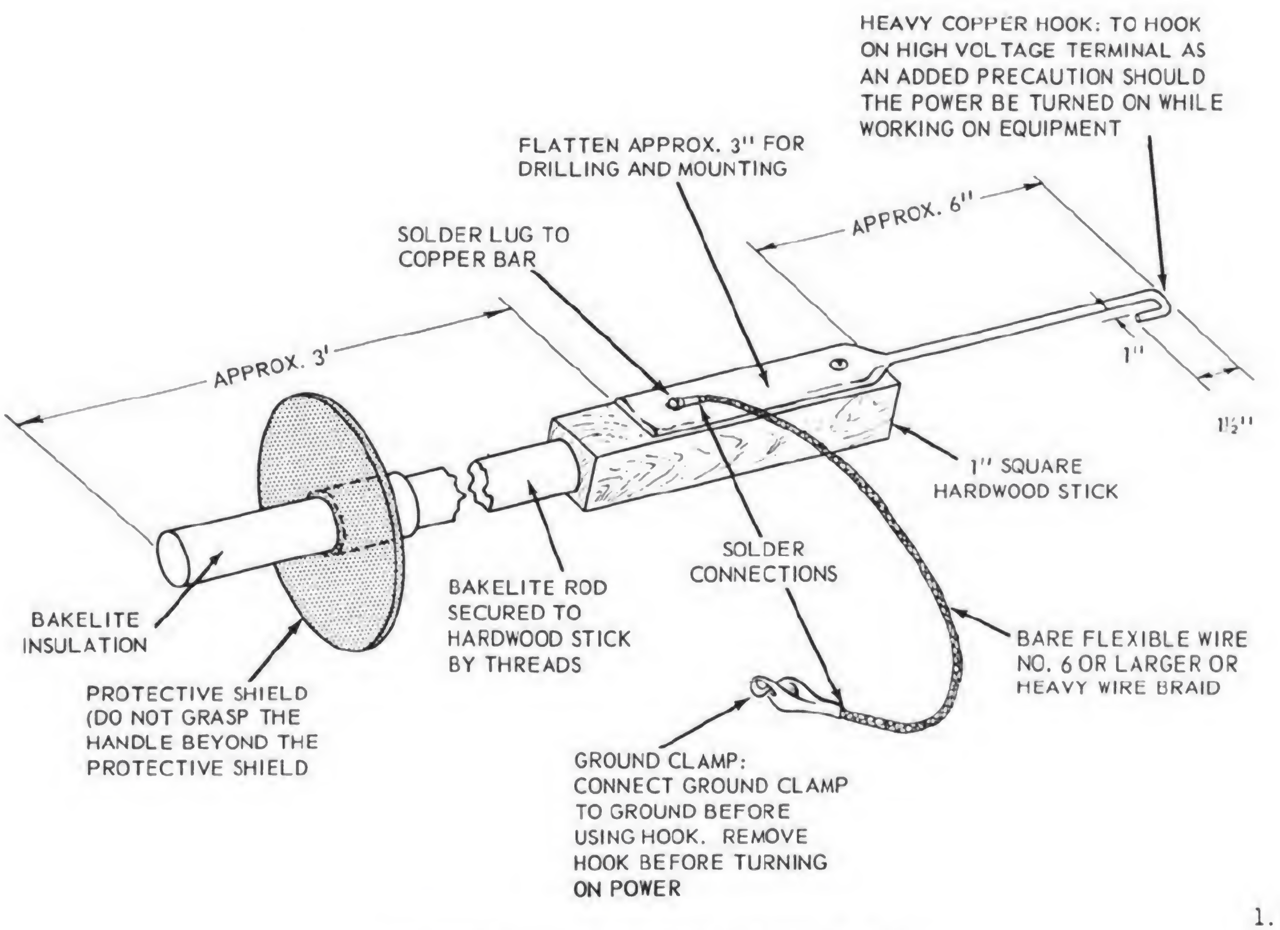


Figure 2-1. —Diagram of a shorting stick.

COMMON SAFETY FEATURES IN ELECTRONIC EQUIPMENT

The CT M should be aware of the safety features that are generally included in electronic equipment. There is a tendency on the part of design people to pay more attention to safety measures when the equipment is to be used by unskilled persons than when it is to be used by skilled persons, but there is always the possibility that an accident will happen to a skilled, but unalert person. This is a matter to keep in mind; and the CT M must remember that safety devices cannot always be counted upon to function.

Some of the common safety features are interlock switches, bleeder resistors, current-limiting resistors, insulated controls, and powerline safety devices.

INTERLOCK SWITCHES

The interlock switch is ordinarily wired in series with the coil of a relay which deenergizes to open contacts in series with the powerline leads to the electronic power supply unit, and is installed on the lid or door of the enclosure so as to break the circuit when the lid or door is opened. A true interlock switch is entirely automatic in action; it does not have to be manipulated by the operator.

Multiple interlock switches, connected in series, may be used for increased safety. One switch may be installed on the access door of a transmitter, and another on the cover of the power supply section. Complex interlock systems are provided when several separate circuits must be opened for safety.

Because electronic equipment may have to be serviced without deenergizing the circuits, interlock switches are so constructed that they can be disabled by the technician. However, they are generally located in such a manner that a certain amount of manipulation is necessary in order to operate them.

BLEEDER RESISTORS

A bleeder resistor is often connected across the output terminals of high voltage d-c power supplies. It is used to bleed the dangerous charges off the filter capacitors because a high-grade filter capacitor can maintain its charge for a long period of time.

The bleeder current is an added drain on the power supply, but the system is designed to withstand this additional burden.

In some equipments where large, high voltage capacitors cannot be effectively shunted by bleeder resistors, the technician must discharge these capacitors before working on the high voltage circuits. For this purpose special shorting sticks are used.

The technician must keep in mind the possibility that the bleeder resistor may burn out and thus become useless as a protective device. Filter capacitors must be discharged as a matter of routine when repair work is to be done. Do not depend on the bleeder; it is merely an added protection.

CURRENT-LIMITING RESISTORS

A current-limiting resistor is often connected in series with the output lead of a high voltage circuit to limit the current (actually, the terminal voltage) to a safe value when a short circuit or an accidental contact occurs. One example is the 1-megohm resistor in the output circuit of high voltage power supplies. Accidental contact loads the circuit in series with the resistor, and most of the high voltage is developed across the resistor instead of across the person making the accidental contact. Bear in mind that a very small current (a few milliamperes) through the body may be fatal. Extreme caution should be exercised at all times when working on live circuits, regardless of the magnitude of the voltage.

INSULATED CONTROLS

Metal knobs, dials, switches, and adjustment screws are generally used only in equipment of the "cold chassis" type; they are not used with a-c/d-c devices (hot chassis).

Even when insulated knobs are used, short setscrews, which do not extend beyond the recessed opening in the knob, are used to prevent the operator's fingers from coming in contact with a possible live circuit. As an added precaution, a spot of sealing wax or coil dope is added to fill in the open end after the setscrew is tightened.

Rheostats and potentiometers in high voltage circuits are placed far enough back of the panel to permit an insulated shaft coupling between the device and the control knob. Common examples are the focus, intensity, and beam-centering controls of an oscilloscope.

POWER-LINE SAFETY MEASURES

Only approved line cords in good condition should be used. Such cords must be protected with insulating grommets at the point where they pass through the chassis or panel.

In addition to the external fuses, equipments are usually supplied with one or more internal fuses.

GROUNDING OF EQUIPMENTS AND COMPONENTS

USE OF GROUNDED-TYPE PLUGS AND RECEPTACLES

Navy specifications for portable tools require that the electric cord for such tools be provided with a distinctively marked ground wire in addition to the conductors for supplying power to the tool. The end of the ground wire within the tool must be connected to the tool's metal housing. The other end must be connected to a positive ground. For this ground connection, specially designed grounded-type plugs and receptacles, which automatically make this connection when the plug is inserted in the receptacle, must be used.

Portable tools not provided with the grounded-type plug, and miscellaneous portable electric equipments, which do not have a cord with a grounded conductor and grounded plug, must be provided with a 3-conductor cord and with a standard Navy grounded-type plug. The ground wire must be connected to a positive ground, and the total resistance from the tool enclosure to the ground to which it is connected must not exceed one ohm.

Because the CT M is responsible for the portable power tools assigned to his division, he must be familiar with the Bureau of Ship's approved methods of installing plugs and cords. The methods are spelled out in detail in Article 60-27 of the <u>Bureau of Ships Technical Manual</u>. The following information is condensed from this article.

All 115-volt or 230-volt single-phase a-c and all 115-volt or 230-volt two wire d-c electrically operated equipment now on board that does not have a cord with a grounding conductor and grounded plug, and all such equipment subsequently issued to the ship without a cord that has a grounding conductor and grounded plug should be provided with a three-conductor flexible cable with standard Navy grounded plug, type D-2-G, shown on Bureau of Ships plan 9-S-4440-L. The three-conductor flexible cable should be type SO or ST color coded black, white, and green, as listed in the Navy Stock List of General Stores, group 61.

All 115-volt 3-phase electrically operated portable equipment now on board or subsequently issued that does not have a cord with a grounding conductor and grounded plug should be provided with a type FHOF four-conductor flexible cable color coded black, white, red, and green, with standard Navy grounded plug, type EEE-125, shown on Bureau of Ships plan 9-S-4861-L.

The length of the cord for portable tools should be 25 feet. The green conductor should be used for the grounding conductor.

Extreme care must be exercised to see that the ground connection is made correctly. If the grounding conductor (green), which is connected to the metallic equipment casing, is connected by mistake to a line contact of the plug, a dangerous potential will be placed on the equipment casing. This might easily result in a fatal shock to the operator. To guard against this danger, the connections must be tested after they have been made, as outlined in <u>Bureau of Ships Technical Manual</u>, chapter 9600, article 9600-27. The tests consist largely of ohmmeter and megohmmeter checks to make certain that the leads are connected properly and that a good ground is assured.

GROUNDING ELECTRONIC EQUIPMENT CASES

Ungrounded electronic equipment cases create an unnecessary hazard and frequently produce electronic interference. All missing ground connections must be replaced, and all ground connections must be checked with an ohmmeter.

GROUNDING WORKBENCHES

Special precautions must be taken to ground workbenches (when used for the repair of electronic equipment) by providing two or more ground straps symmetrically placed at diagonally opposite corners or posts, using low-resistance flexible braid securely welded or bolted to steel deck or bulkhead. After completing the grounding of the bench, it is tested with a low-reading ohmmeter for positive grounding. Positive ground will be indicated by a low meter reading of less than one ohm.

PRECAUTIONS AGAINST ACCIDENTAL ENERGIZING

SECURING SWITCHES

When electrical equipment is to be worked on it must be disconnected from the source of supply by opening main or branch supply switches, circuit breakers, or cutouts so as to completely eliminate the possibility of current flowing to the equipment. Switches, circuit breakers, or cutouts opened for this purpose must be secured in the open position and must have tags attached. Only the individual placing the tag may remove it and reenergize the circuit. Specific instructions are given in United States Navy Safety Precautions, OpNav 34P1, Chapter 18.

INDUCED VOLTAGES

Electronic equipment operating in the high frequency range causes voltages to be induced in the standing rigging and other portions of a ship's structure or in metal objects such as bracing or guy wires around a land-based transmitting station. Under certain conditions these induced voltages can be considered hazardous. The voltages caused by resonant circuits set up in such objects or rigging will cause shock to personnel or produce open sparks when contact is made or broken; for example, when the circuit is opened, or when metallic objects make contact with the structure.

Although there are too many variables to give even an approximation of the voltages that may be encountered, excessive radiofrequency pickup from ship's antennas has been observed on stack guys, davit head spans, and the like. A similar high-frequency pickup has been observed on board ships reeling in or paying out wire cable or hawsers when the length becomes resonant to the emitted frequency. It has also been discovered that flammable liquids may be ignited in close proximity to an energized radar antenna if the liquid is in a metal container or near metal objects.

PRECAUTIONS WHEN WORKING ON ANTENNAS

Personnel must be cautioned not to venture or work close to an exposed radio transmitter antenna unless it is first determined from the proper authority that the antenna is not and will not be energized.

Specific instructions covering working aloft are given in Section 3, Chapter 18, of United States Navy Safety Precautions, OpNav 34P1, a portion of which is included in the following paragraphs.

"Before any work may be done aloft, authorization must be obtained from the commanding officer. (The OOD usually gives permission for the commanding officer.) While antennas are energized by radio transmitters, men shall not be permitted to go aloft except by means of ladders and platforms rendered safe by grounded handrails or similar structures. Before sending men aloft, except as noted previously, the commanding officer shall direct the communication watch officer to secure the proper transmitter in order to render safe this area. If the installation is aboard ship, he shall also notify the engineer duty officer that men will be working in a prescribed area aloft in order that the engineer duty officer may take the necessary precautions to prevent the boiler safety valves from lifting (these are vented up the stack). Until he has received a report from the communication watch officer that the proper transmitters are secured, the commanding officer shall permit no man to go aloft. After the work has been completed, a report shall be made to the commanding officer, and his authorization must be obtained before the circuit is again energized."

"Antennas which rotate or swing through horizontal or vertical arcs may cause men working aloft to fall. Therefore, the motor switches which control the motion of these antennas shall be locked open and tagged before men are permitted to ascend or go within reach of them."

In connection with antennas it is extemely important to maintain a safe distance (perhaps hundreds of feet) in the field of an antenna of a high-powered transmitter. At least one instance has been reported in which a man suffered fatal internal burns when he stood briefly in front of an energized high-powered radar antenna.

PRECAUTIONS WHEN HANDLING ELECTRON TUBES

CATHODE-RAY TUBES

The use of larger cathode-ray tubes has increased the danger of implosion, flying glass, and injury from high voltage. The danger is greatly reduced if the tubes are properly handled.

If they are handled carelessly, struck, scratched, or dropped, they can very well become an instrument of severe injury or death. The following precautions should be taken: (1) Goggles shall be worn to protect the eyes from flying glass particles, (2) suitable gloves shall be worn, and (3) no part of the body should be directly exposed to possible glass splinters caused by implosion of the tube. (The inner coating on some tubes is poisonous if absorbed into the blood stream.)

Cathode-ray tubes must not be unnecessarily exposed to possible damage. When a tube is being unpacked, it should be removed from the packing box with caution, taking care not to strike or scratch the envelope. Insert it into the equipment socket cautiously, using only moderate pressure. When the tube must be set down, it is important that it be placed on a clean, soft padding. If special tube-handling equipment is available, it should be used according to instructions.

It is well to realize, too, that X rays are generated at the surface of cathode-ray tubes. At voltages of less than 15,000 volts, the glass is a shield. Above 15,000 volts the glass is progressively a poorer shield as the voltage goes up.

RADIOACTIVE ELECTRON TUBES

Electron tubes containing radioactive material are listed in Section 7, of EMB. Future contracts negotiated by the Electronic Supply Officer for the tube types listed in the reference EMB will provide that the tubes be tagged: "Radioactive—Do Not Handle Broken Tubes" and "Do Not Remove From Cartons Until Ready For Use."

Poisoning from radioactive materials in the subject electron tubes may be of three types.

1. ASSIMILATION—Eating, drinking, or breathing radium or radium compounds or absorbing them through cuts. Radium-bearing dust, which may be present in certain tubes, is dangerous in this respect.
2. BREATHING RADON—Radon is a tasteless, odorless, colorless gas that is given off by radium and radium compounds at all times. When breathed into the lungs it may cause severe injury.
3. RADIATION—Radium and radium compounds give off harmful, invisible radiations that can cause dangerous burns.

Radium bromide is used in spark-gap, glow-lamp, and cold cathode tubes.

Glow lamps and cold cathode tubes contain from 0.01 to 1.0 micrograms of equivalent radium per tube. Spark gap tubes contain from 1.0 to 2.0 micrograms of equivalent radium per tube.

Radium bromide causes the formation of radon gas within the tube envelope, and it is dangerous to inhale this gas. Radium salts are cumulative poisons and, like other radioactive concentrations, are extremely hazardous if injected anywhere into the human system.

PRECAUTIONS TO BE OBSERVED WHEN PAINTING ELECTRONIC EQUIPMENT

Adequate ventilation must be provided for all enclosed compartments in which painting is to be done. Exhaust ventilators as well as power blowers should be used. Blowers should be so arranged as to ensure rapid and complete removal of all explosive, combustible, or toxic vapors which may be present. Vapors must be exhausted in such a way that they will not be sucked into any of the ship's supply vents which may be running, or in any way contaminate other areas.

Where paint vapors or fumes are known to be explosive, any electrical equipment used in the vicinity of the painting operations in enclosed compartments must be of the explosion-proof type. Do not permit smoking or allow any type of work that may produce flames or sparks to be performed within the danger area.

Maintain good housekeeping practices, keep all unnecessary objects and materials stowed and out of the way. Particular attention must be given to rags, sweepings, waste, etc., which may be paint-saturated or contaminated. These materials must be placed in covered metal containers or buckets containing water.

The exits to the compartment in which painting is being done must not be blocked in any manner. Adequate firefighting equipment must be at hand.

PRECAUTIONS WHEN USING SOLVENTS

Carbon tetrachloride is definitely toxic, actually about four times as toxic as carbon monoxide, and serious accidents have resulted from the improper use, storage, and handling of this solvent.

A new solvent, methyl chloroform, has been approved for cleaning electrical and electronic equipment. It is now available from General Stores, and should be used in place of the more dangerous carbon tetrachloride.

The Chemistry Branch of the Bureau of Ships initiated the test program that resulted in the introduction of the new solvent.

Even though methyl chloroform is less toxic than carbon tetrachloride, the solvent does present some hazards to personnel, and the following precautionary note is required on the container label:

"Caution—Use with adequate ventilation. Avoid prolonged or repeated breathing of vapor. Avoid prolonged or repeated contact with skin. Do not take internally."

The solvent may be applied by wiping, brushing, or spraying, Methyl chloroform, like carbon tetrachloride, will attack electrical insulating materials, particularly the air-dried varnishes. Therefore contact time should be limited.

SOME RULES TO REMEMBER

1. Do not rely on safety devices such as interlocks and high-voltage relays.
2. Do not work alone on high-voltage circuits.
3. Observe all warning signs.
4. Do not intentionally come in contact with an energized circuit.
5. Avoid working on energized circuits.
6. Do not smoke, eat, or drink while painting.
7. Remember that solvents are potentially dangerous.
8. Use a shorting stick for discharging capacitors.
9. Use approved fuse pullers.
10. The appearance of the work is a measurement of the worker's ability; the same is true of the work space.
11. Remember that personnel may be killed or injured by high voltage equipment that is assumed to be off. Take nothing for granted. Make certain that the power is off by securing the powerline switch in the OFF position.
12. Observe carefully the instructions about tagging open switches. The following is quoted from Chapter 9670, Article 9670-289 of the Bureau of Ships Technical Manual.

"When any electronic equipment is to be overhauled or worked on, the main supply switches or cutout switches in each circuit from which power could possibly be fed shall be secured in the open (or safety) position and tagged. The tags shall read 'This circuit was ordered open for repairs and shall not be closed except by direct order of ___' (usually the person making, or directly in charge of, the repairs). After the work has been completed, the tag or tags shall be removed by the same person. "When more than one repair party is engaged in the work, a tag for each party shall be placed on the supply switch. Each party shall remove only its own tag upon completion of the work."

"When switch-locking facilities are available, the switch shall be locked in the open (SAFETY) position and the key retained by the person doing the work so that only he, or a person designated by him, can remove the lock and restore the circuit."

13. Even after switches have been opened and tagged, make an additional check at the equipment with a voltmeter known to be in good working order to ensure that the correct switch or switches have been opened.
14. Remember that aboard ship a person must exercise the greatest precaution when working with electrical circuits because of the metal structure (good ground), dampness, and oftentimes crowded working conditions. This does not mean that a technician should be less cautious at shore stations. He should be cautious whenever he works with electricity; but, in general, the chances of being injured aboard ship are greater if the necessary additional precautions are not taken.
15. Be thoroughly familiar with United States Navy safety precautions, especially Section V of Chapter 9670 of the Bureau of Ships Technical Manual, NavShips 250,000.

CHAPTER 3

DESIGNATION SYSTEMS AND ELECTRONICS ADMINISTRATION

As a CT M you will be responsible for preparing maintenance records and reports, and may be responsible for maintaining, ordering, and requisitioning spare or replacement parts and equipments. Naval equipment and parts are identified by a standard system of designators. Since all records, reports, and ordering of parts will require a knowledge of equipment and parts designators, the first portion of this chapter is devoted to a discussion of the systems in use in the Navy today. The remainder of the chapter is devoted to records, supply systems, and related information that is of importance to the CT M. The forms associated with each topic are also discussed.

EQUIPMENT DESIGNATORS

There are two Navy designation systems—The Numerical System of Navy Type Designations, and the Alphabetical System of Navy Type Designations.

THE NUMERICAL SYSTEM

The numerical designation system is composed of a Navy type number (e.g., 21426) and a group of prefix letters to indicate the manufacturer of the item (e.g., CZZ). The prefix letters and the navy type number are separated by a dash to form the complete navy type designation (e.g., CZZ-21426). Once prefix letters are assigned to a manufacturer they remain the permanent identification of the company and shall precede the navy type numbers of all material manufactured by it. The first two numbers are the class and the last three or four are simply assigned in numerical order as parts are added to the list (Manufacturers Designating Symbols are listed in NavShips 900,152).

THE ALPHABETICAL SYSTEM

The Alphabetical System is used for units peculiar to radar equipments and special apparatus, and is analogous to the numerical system except the last three of four numbers of the numerical portion are replaced with alphabetical letters starting with AAA and progressing alphabetically; (e.g., CRV-36 AAC). The application of both systems of Navy type designations are the same.

JOINT ELECTRONICS TYPE DESIGNATION SYSTEM (AN SYSTEM)

The Electronic Type Designator System (AN System) for electronic equipment was adopted in 1943. The system is designed to:

1. Be logical in principle so that the nomenclature type numbers will be readily understood, and the operation of the armed forces supply services will be facilitated.
2. Be flexible and sufficiently broad in scope to cover present types of equipment and new types and uses of equipment that will be developed in the future.
3. Avoid conflict with nomenclature at present assigned to the equipment used by the armed services.
4. Provide adequate identification on nameplates with or without the name part of the nomenclature.
5. Provide a ready menas of identifying equipment in correspondence and other types of communication.

The system is designed so that its indicators will tell at a glance many things that pertain to the item. For example, it tells whether the item is a SET or a UNIT and such other information as where it is used, what kind of equipment it is, and what it is used for. (See table 3-1.)

Table 3-1.--Equipment Indicator Letters.

1	2	3	4	5	6
Installation	Type of Equipment	Purpose	Model Number	Modification Letter	Miscellaneous Identification
A—Airborne (installed and operated in aircraft) B—Underwater mobile, submarine C—Air transportable (inactivated, do not use) D—Pilotless carrier F—Fixed G—Ground, general ground use (include two or more ground type installations) K—Amphibious M—Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment) P—Pack or portable (animal or man)	A—Invisible light, heat radiating B—Pigeon C—Carrier D—Radiac E—Nupac (nuclear protection and control) F—Photographic G—Telegraph or teletype I—Interphone and public address J—Electro-mechanical (not otherwise covered) K—Telemetering L—Countermeasures M—Meteorological N—Sound in air P—Radar Q—Sonar and underwater sound R—Radio S—Special types, magnetic, etc., or combinations of types T—Telephone (wire) V—Visual and visible light W—Armament (peculiar to armament, not otherwise covered)	A—Auxiliary assemblies (not complete operating sets used with or part of two or more sets or sets series) B—Bombing C—Communications (receiving and transmitting) D—Direction finder and/or reconnaissance E—Ejection and/or release G—Fire control or searchlight directing H—Recording and/or reproducing (graphic meteorological and sound) K—Computing L—Searchlight control (inactivated, use "G") M—Maintenance and test assemblies (including tools) N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach and landing) P—Reproducing (inactivated, do not use) Q—Special, or combination of purposes	1 2 3 4 Etc.	A B C D Etc.	X, Y, Z —change in input voltage, phase, or frequency Experimental indicators XA—Communications—Navigation Laboratory, WADC, Dayton, Ohio XB—Naval Research Laboratory, Washington, D.C. XD—Cambridge Research Center, Cambridge, Mass. XF—Frankfort Arsenal, Philadelphia, Pa. XG—U.S.N. Electronic Laboratory, San Diego, Calif. XH—Aerial Reconnaissance Laborabory, WADC, Dayton, Ohio XJ—Naval Air Development Center, Johnsville, Pa. XK—Flight Control Laboratory, WADC, Dayton, Ohio XL—Signal Corps Electronics Research Unit, Mountain View, Calif.

Table 3-1.—Equipment Indicator Letters—Continued.

1	2	3	4	5	6
Installation	Type of Equipment	Purpose	Model Number	Modification Letter	Miscellaneous Identification
S—Water surface craft T—Ground, transportable U—General utility (includes two or more general installation classes, airborne, shipboard, and ground) V—Ground, vehicle (installed in vehicle designed for functions other than carrying electronic equipment etc., such as tanks) W—Water surface and underwater	X—Facsimile or television Y—Data processing	R—Receiving, passive detecting S—Detecting and/or range and bearing T—Transmitting W—Control X—Identification and recognition			XN—Department of the Navy, Washington, D. C. XO—Redstone Arsenal, Huntsville, Ala. XP—Canadian Department of National Defense, Ottawa, Canada XS—Electronic Components Laboratory, WADC, Dayton, Ohio XU—U.S.N. Underwater Sound Laboratory, Fort Trumbull, New London, Conn. XW—Rome Air Development Center, Rome, N.Y. XAN—Naval Air Facility, Indianapolis, Ind. For complete details see MIL-STD-196 publication

Table 3-2.—Designation For Radar Set AN/APS-2.

Radar Set	AN/	A	P	S-	2
Item name as prescribed	A major equipment	See the designated column in table 3-1.			Second equipment in this category (col. 4)
		Airborne (col. 1)	Radar (col. 2)	Search (col. 3)	

Table 3-3.—Table of Component Indicators.

Comp Ind.	Family Name	Examples of Use (Not to be construed as limiting the application of the component indicator)
AB	Supports, Antenna	Antenna mounts, mast bases, mast sections, towers, etc.
AM	Amplifiers	Power, audio, interphone, radio frequency, video, electronic control, etc.
AS	Antennae, Complex	Arrays, parabolic type, mast-head, etc.
AT	Antennae, Simple	Whip or telescopic, loop, dipole, reflector, etc.
BA	Battery, primary type	B batteries, battery packs, etc.
BB	Battery, secondary type	Storage batteries, battery packs, etc.
BZ	Signal Devices, Audible	Buzzers, gongs, horns, etc.
C	Controls	Control box, remote tuning control, etc.
CA	Commutator Assemblies, Sonar	Peculiar to sonar equipment
CB	Capacitor Bank	Used as a power supply
CG	Cable Assemblies, R.F.	R.F. cables, waveguides, trans-mission lines, etc., with terminals
CK	Crystal Kits	A kit of crystals with holders
CM	Comparators	Compares two or more input signals
CN	Compensators	Electrical and/or mechanical com-pensating, regulating or attenu-ating apparatus
CP	Computers	A mechanical and/or electronic mathematic calculating device
CR	Crystals	Crystal in crystal holder
CU	Couplers	Impedance coupling devices, direc-tional couplers, etc.
CV	Converters (electronic)	Electronic apparatus for changing the phase, frequency, or from one medium to another
CW	Covers	Cover, bag, roll, cap, radome, nacelle, etc.
CX	Cable Assemblies, Non-R.F.	Non-R.F. cables with terminals, test leads, also composite cables of R.F. and non-R.F. conductors
CY	Cases and Cabinets	Rigid and semirigid structure for enclosing or carrying equipment

Table 3-3.—Table of Component Indicators—Continued.

Comp Ind.	Family Name	Examples of Use (Not to be construed as limiting the application of the component indicator)
D	Dispensers	Chaff dispensers
DA	Load, Dummy	R.F. and non-R.F. test loads
DT	Detecting Heads	Magnetic pick-up device, search coil, hydrophone, etc.
DY	Dynamotors	Dynamotor power supply
E	Hoists	Sonar hoist assembly, etc.
F	Filters	Band-pass, noise, telephone, wave traps, etc.
FN	Furniture	Chairs, desks, tables, etc.
FR	Frequency Measuring Devices	Frequency meters, tuned cavity, etc.
G	Generators, Power	Electrical power generators without prime movers. (See PU and PD.)
GO	Goniometers	Goniometers of all types
GP	Ground Rods	Ground rods, stakes, etc.
H	Head, Hand, and Chest Sets	Includes earphone
HC	Crystal Holder	Crystal holder less crystal
HD	Air Conditioning Apparatus	Heating, cooling, dehumidifying, pressure, vacuum devices, etc.
ID	Indicators, Non-Cathode-Ray Tube	Calibrated dials and meters, indicating lights, etc. (See IP.)
IL	Insulators	Strain, standoff, feed-through, etc.
IM	Intensity Measuring Devices	Includes SWR gear, field intensity and noise meters, slotted lines, etc.
IP	Indicators, Cathode-Ray Tube	Azimuth, elevation, panoramic, etc.
J	Junction Devices	Junction, jack and terminal boxes, etc.
KY	Keying Devices	Mechanical, electrical and electronic keyers, coders, interrupters, etc.
LC	Tools, Line Construction	Includes special apparatus such as cable plows, etc.
LS	Loudspeakers	Separately housed loudspeakers, intercommunication station
M	Microphones	Radio, telephone, throat, hand, etc.
MA	Magazines	Magnetic tape or wire, etc.
MD	Modulators	Device for varying amplitude, frequency or phase
ME	Meters, Portable	Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc.
MF	Magnets or Magnetic Field Generators	Magnetic tape or wire eraser, electro-magnet, permanent magnet, etc.

Table 3-3.—Table of Component Indicators—Continued.

Comp Ind.	Family Name	Examples of Use (Not to be construed as limiting the application of the component indicator)
MK	Miscellaneous Kits	Maintenance, modification, etc., except tool and crystal. (See CK, TK.)
ML	Meteorological Devices	Barometer, hygrometer, thermometer, scales, etc.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified Do not use if better indicator is available
O	Oscillators	Master frequency, blocking, multivibrators, etc. (For test oscillators, see SG.)
OA	Operating Assemblies	Assembly of operating units not otherwise covered
OC	Oceanographic Devices	Bathythermographs, etc.
OS	Oscilloscope, Test	Test oscilloscopes for general test purposes
PD	Prime Drivers	Gasoline engines, electric motors, diesel motors, etc.
PF	Fittings, Pole	Cable hangar, clamp, protectors, etc.
PG	Pigeon Articles	Container, loft, vest, etc.
PH	Photographic Articles	Camera, projector, sensitometer, etc.
PP	Power Supplies	Nonrotating machine type such as vibrator pack, rectifier, thermoelectric, etc.
PT	Plotting Equipments	Except meteorological. Boards, maps, plotting table, etc.
PU	Power Equipments	Rotating power equipment except dynamotors. Motor-generator, etc.
R	Receivers	Receivers, all types except telephone
RC	Reels	Reel, cable. (See RL.)
RD	Recorder-Reproducers	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc.
RE	Relay Assemblies	Electrical, electronic, etc.
RF	Radio Frequency Component	Composite component of R.F. circuits. Do not use if better indicator is available.
RG	Cables, R.F., Bulk	R.F. cable, waveguides, transmission lines, etc., without terminals

Table 3-3.—Table of Component Indicators—Continued.

Comp Ind.	Family Name	Examples of Use (Not to be construed as limiting the application of the component indicator)
RL	Reeling Machines	Mechanisms for dispensing and rewinding antenna or field wire, recording wire or tape, etc.
RO	Recorders	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc.
RP	Reproducers	Sound, graphic, tape, wire, film, disc, facsimile, magnetic, mechanical, etc.
RR	Reflectors	Target, confusion, etc. Except antenna reflectors. (See AT.)
RT	Receiver and Transmitter	Radio and radar transceivers, composite transmitter and receiver, etc.
S	Shelters	House, tent, protective shelter, etc.
SA	Switching Devices	Manual, impact, motor driven, pressure operated, etc.
SB	Switchboards	Telephone, fire control, power, panel, etc.
SG	Generators, Signal	Test oscillators, noise generators, etc. (See O.)
SM	Simulators	Flight, aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions
ST	Straps	Harness, straps, etc.
T	Transmitters	Transmitters, all types except telephone
TA	Telephone Apparatus	Miscellaneous telephone equipment
TD	Timing Devices	Mechanical and electronic timing devices, range device, multiplexes, electronic gates, etc.
TF	Transformers	Transformers when used as separate items
TG	Positioning Devices	Tilt and/or Train Assemblies
TH	Telegraph Apparatus	Miscellaneous telegraph apparatus
TK	Took Kits	Miscellaneous tool assemblies
TL	Tools	All types except line construction. (See LC.)
TN	Tuning Units	Receiver, transmitter, antenna, tuning units, etc.
TR	Transducers	Magnetic heads, phono pickups, sonar transducers, vibration pickups, etc. (See H, LS, and M.)
TS	Test items	Test and measuring equipment not otherwise included; boresighting and alignment equipment.

Table 3-3.—Table of Component Indicators—Continued.

Comp Ind.	Family Name	Examples of Use (Not to be construed as limiting the application of the component indicator)
TT	Teletypewriter and Facsimile Apparatus -----	Miscellaneous tape, teletype, facsimile equipment, etc.
TV	Tester, Tube ------------------------	Electronic tube tester
TW	Tapes and Recording Wires --------------	Recording tape and wire, splicing, electrical insulating tape, etc.
U	Connectors, Audio and Power ------------	Unions, plugs, sockets, adapters, etc.
UG	Connectors, R.F. ---------------------	Unions, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
V	Vehicles -------------------------	Carts, dollies, trucks, trailers, etc.
VS	Signaling Equipment, Visual -------------	Flag sets, aerial panels, signal lamp equipment, etc.
WD	Cables, Two Conductor -----------------	Non-r.f. wire, cable and cordage in bulk. (See RG.)
WF	Cables, Four Conductor ----------------	Non-r.f. wire, cable and cordage in bulk. (See RG.)
WM	Cables, Multiple Conductor --------------	Non-r.f. wire, cable and cordage in bulk. (See RG.)
WS	Cables, Single Conductor ---------------	Non-r.f. wire, cable and cordage in bulk. (See RG.)
WT	Cables, Three Conductor ---------------	Non-r.f. wire, cable and cordage in bulk. (See RG.)
ZM	Impedance Measuring Devices ------------	Used for measuring Q, C, L, R or PF, etc.

Set Identification

To explain the system, a typical example of set nomenclature, Radar Set AN/APS-2, is included in table 3-2. Thus, Radar Set AN/APS-2 is a search radar set installed and operated in an aircraft.

Other equipments in the same category are the AN/APS-4 and AN/APS-6. Another set of a different category is the AN/SRC-1 which, as indicated in table 3-1, is a shipboard radio communications set for receiving and transmitting.

To identify a set that has been modified, but which still retains the basic design and is interchangeable with the unmodified set, a modification letter is used (see table 3-1, column 5). Thus, if Radar Set AN/APS-2 is modified, it becomes AN/APS-2A. The next modification would be the AN/APS-2B, and so on.

A special indicator (see table 3-1, column 6) is used when the only change to a set is in its input power, or when it is an experimental or a special model. For example, if the same basic design is kept but the input power is changed

from 13 volts to 26 volts, the letter "X" is added to the nomenclature, as AN/APS-2AX. The second power input change would be identified by the letter "Y".

A special indicator (T) for training sets is also available and is used in conjunction with the other indicators to show that it is a training set for a specific equipment. Likewise, it may be used to indicate a trainer for a special family of equipment. For example, the first training set for the AN/APS-2 would be AN/APS-2T1.

The system also provides for identifying a series of sets by the use of parentheses after the type number. Thus, the AN/APS-2( ) refers to the AN/APS-2 set and all its modifications such as the AN/APS-2A, AN/APS-2B, as well as its experimental versions such as the AN/APS-2(XB-1).

Experimental sets are identified by the use of the development organization indicators (see table 3-1, column 6). A number is used to indicate a particular developmental or reproduction model. Thus, the first developmental model of the AN/APS-2 could be identified as the AN/APS-2(XB-1), assuming, of course, that the Naval Research Laboratory did the work.

Component Identification

So far, consideration has been given only to the indicators used in SET nomenclature. Indicators for major COMPONENTS of a set are now considered.

Components are identified by means of indicating letters (which tell the type of component it is) (see table 3-3), a number (which identifies the particular component), and finally the designation of the equipment of which it is a part or with which it is used.

For example, the receiver for the AN/APS-2 would be identified (table 3-4) as follows:

Table 3-4.—Designation of Components.

Radar Receiver	R	7	/APS-2
Item name as prescribed	From table 3	The 7th receiver to which an "AN" designation has been assigned	The set it is used with or is a part of

Thus, the R-7/APS-2 is a receiver that is used with or is a part of airborne radar search set No. 2. Another receiver, such as the R-8/ARN-8, would be indicated by the tables as a receiver used with or as a part of airborne radio navigation set No. 8.

To identify a component that has been modified but which still retains the basic design and is interchangeable physically, electrically, and mechanically with the modified item, a modification letter is used, as on sets. Thus, the R-7A/APS-2 would be a modified version of the R-7/APS-2.

Components that are part of or used with two or more sets are identified in the usual way, except that after the slant bar, there will appear only those indicators that are appropriate and without a set model number. Thus, a modulator that is part of or used with the AN/APS-2 and the AN/APS-6 might be identified as MD-8/APS.

NAVY MODEL LETTER SYSTEM

The assignment of a particular model letter to Navy equipments depends on the primary function of the equipment, such as receiving, direction finding, etc. This system of assigning model letters is applicable to all radio, radar, and sonar equipments and once learned, makes easy the recognition and identification of all Navy equipments.

In this system, the first letter indicates the basic purpose of the equipment. These designations, which are listed in table 3-5, are followed by another letter of the alphabet to indicate the

Table 3-5.—Navy Model Letters.

Model Letters	Primary Function of the Equipment
A	Airborne—used as a prefix to indicate airborne installation as: AR series —airborne radio receiving, etc.
B	IFF
CX	Commercial experimental
D	Radio direction finding
E	Emergency power
FS	Frequency-shift keying
G	Formerly aircraft transmitting (now superseded by "A" series)
J	Sonar listening (receiving)
K	Sonar transmitting
L	Precision calibrating
M	Combined radio transmitting and receiving
MARK	Fire-control radar
N	Sonar navigational aids including echo sounding
O	Measuring and operator training
P	Automatic transmiting and receiving
Q	Sonar ranging
R	Radio receiving
S	Search radar
T	Radio transmitting (includes combination transmitting and receiving)
U	Remote control (includes automatic keyers)
V	Radar repeaters
W	Combined sonar ranging and sounding
X	Naval experimental
Y	Navigational and landing aids
Z	Navigational and landing aids (airborne)—superseded by model Y series

order in which designations are assigned. Thus, TA was the first transmitting equipment assigned, TB, the next, etc. When the alphabet was exhausted, triple letters were used—for example, TAA. The order of assignment was then indicated by a change in the third letter. Thus, the model letter assigned after TAA was TAB. When the alphabet was again exhausted, a third series of model letters was formed by changing the second letter to B—for example, TBA, TBB----------------TBS--------------.

Numbers following model letters indicate a modification of the equipment or the award of a new contract. To indicate a change in equipment after delivery has been made, lower case letters are assigned.

The Navy model letter system of equipment designation is no longer in primary use, now that the AN system has been instituted. There are, however, still some equipments with this type of designation in the naval establishment.

The Navy model letters used in sonar equipment are shown in table 3-6. The first letter indicates the general use of the equipment. The second letter of the "Q" series equipment designates the type of projector used, as indicated in table 3-6.

Table 3-6.—Navy Model Letters Used In Sonar Equipment.

Model Letters	Type of Projector Used
QA	Quartz steel
QB	Rochelle salt
QC	Magnetostriction
QD	Depth determining (not echo sounding)
QG	Magnetostriction—split-lobe type
QH	Scanning sonar

WIRING DIAGRAMS

Wiring diagrams are shorthand records (with symbols) which represent electronic equipments and their terminals. Primarily, these diagrams indicate which terminals are interconnected with wires.

The uses, arrangements, and interpretation of symbols are found in MIL-STD-15-1, entitled

Military Standards of Graphical Symbols for Electrical and Electronic Diagrams, Part 1. Information on this subject is given also in Blueprint Reading and Sketching, NavPers 10077-B.

Not only do symbols and usages change from time to time but new ones are introduced. Accordingly, it is well to check current publications (diagrams versus standard symbols).

SWITCHING AND FUSING DESIGNATIONS

Possible switching designations are illustrated in figure 3-1. If switch "S" is designed to be used with the equipment, the markings would be as shown in part A. If switch "S" is Government supplied, the terminals would be marked differently, perhaps as 1A through 6A, as illustrated in part B.

TERMINAL DESIGNATIONS

The following information condensed from Dictionary of Standard Terminal Designations for Electronic Equipment, NavShips 900,186, will be helphul to the CT M.

TERMINAL BOARDS

Terminal boards are marked with a three-or four-digit number preceded by "TB." This marking is easily identified by the technician. The first one or two digits of the "TB" number represent the unit number in an equipment. This number is assigned by the manufacturer in a logical order. The last two digits represent the terminal board number in a unit, starting with 01, 20, 03,---------11, 12, 13, etc. Thus, a terminal board marked TB1003 indicates the third terminal board in the 10th unit of an equipment.

As an example, an equipment might be composed of a transmitter, a receiver, and a power supply, with the transmitter having six external terminal boards, the receiver four external terminal boards, and the power supply two external terminal boards. The manufacturer will then assign numbers to the units—perhaps 1 for the transmitter, 2 for the receiver, and 3 for the power supply. Figure 3-2 shows how the terminal boards would then be marked.

TERMINAL MARKING

The marking of terminals on terminal boards indicates a specific function for the following circuits: (1) common primary power circuits, (2) ground terminals, (3) common servo and synchro circuits, (4) video circuits, (5) trigger circuits, and (6) audio circuits. The breakdown of these categories into specific functions, with the terminal designation of each, is listed in NavShips 900,186. These are RIGIDLY ASSIGNED DESIGNATIONS.

Terminals whose functions do not fall under the categories listed are assigned designations by the equipment manufacturer in accordance with NavShips 900,186. These are MANUFACTURER-ASSIGNED DESIGNATIONS.

Only those terminals that will be connected together externally will have exactly the same designation within any given equipment.

RIGIDLY ASSIGNED DESIGNATIONS—Functional designations for circuits in the previously listed categories may be recognized by a one- or two-digit number preceded by a single or double letter (I and O are not used) such as S1, S2, S11, SS11, etc. These designations are stamped or engraved on the terminal board beside each terminal, as shown in figure 3-3.

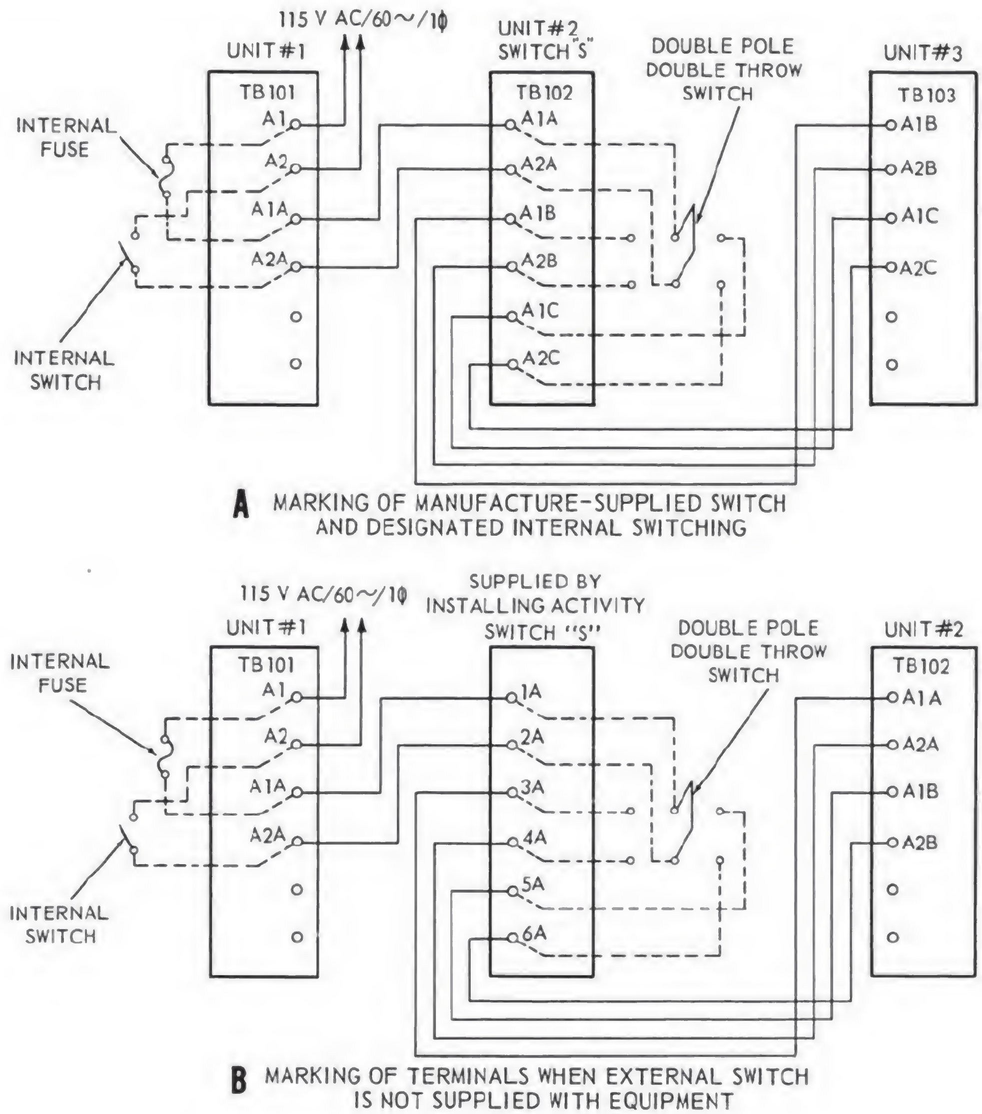
If the same function appears more than one time in an equipment it is distinguished by the addition of a letter or letters after the designation, beginning with "A," as shown in figure 3-4.

If more than 25 sets of terminals have the same function in an equipment, the letter following is then doubled (for example, S1AA). If these letters are used up, combinations of letters (for example, S1AB) are used.

MANUFACTURER—ASSIGNED DESIGNATIONS.—These designations begin with a number rather than a letter, as opposed to rigidly assigned designations.

When a "nonrigidly assigned" function is brought out to a terminal, the manufacturer assigns 1A to the first such terminal and also 1A to the terminal that is to be tied to this point. The designation, 1A, does not appear again unless it is to be tied directly to either of the terminals already marked.

As more manufacturer-assigned designations are used, 2A, 3A---------99A are used; then 1B, 2B--------99B and up to 1Z, 2Z-----------------99Z (omitting I and O) are used. If additional numbers are needed,



70.4

Figure 3-1.—Possible switching and fusing designations.

the letters are doubled or combinations of two letters are used.

ORDER OF TERMINALS ON TERMINAL BOARD

All circuits of a given function on a terminal board are grouped and arranged in a particular order. This grouping applies for rigidly assigned and manufacturer-assigned designations. Primary power circuits, unless connected to a separate fuse block instead of a terminal board proper, are the first connections on a terminal board. Synchro/servo circuits are arranged in sequence of reference or excitation. No particular position or area of any terminal board is reserved for a synchro function, but a logical order is illustrated in figure 3-5.

All circuits of each video, trigger, or audio function will appear in sequence, each with its associated ground where such ground is unique to that particular function.

CONDUCTOR MARKING

On the conductor lead, at the end near the point of connection to a terminal post, spaghetti sleeving is used as a marking material and insulator. The sleeving is engraved with indelible ink, or branded with identifying numbers and letters by a varitype machine, and slid over the conductor.

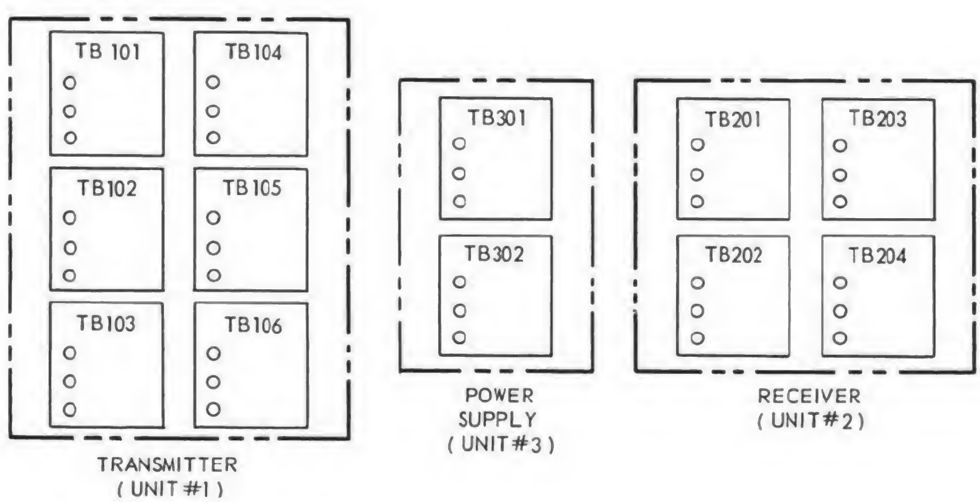
The order of marking is such that the first appearing set of numbers and letters reading from left to right will be the designation corresponding to the terminal to which that end of the wire is connected. Following this, there is a dash and then the number (without the "TB") of the terminal board to which the other end of the conductor is attached. There is another dash and then the designation of the particular terminal to which the other end of the wire is connected. For example, assume that a conductor of a cable runs between units Nos. 1 and 2 of an equipment. The terminal boards are TB001 and TB002, and the terminals are designated A1 on both terminal boards. Figure 3-6A shows the order and method of marking spaghetti sleeving under these conditions. Figure 3-6B illustrates conductor marking between unlike terminals.

LEAD DESIGNATIONS ON SCHEMATIC DIAGRAMS

Navy receivers are compartmentalized into assemblies and subassemblies. All circuits to an assembly (with certain exceptions) are disconnected when the assembly is lifted from the chassis and connected when the assembly is fitted into position. The individual subassemblies consist of a subminiature electron tube and the circuit for one stage. The subassembly plugs into an appropriate socket of the assembly. The circuits terminate in connector receptacles, as illustrated in figure 3-7. Each terminal is identified by letter. Where connecting leads merge into a single cable the identity of the individual circuits is maintained by letter-number designation. For example, the Out-Hi lead to terminal L of J126 is connected through the matching connector receptacle plug-jack arrangement to L of J253. The outgoing lead is marked J254-B. This lead is marked at terminal B of J254 as J253-L. Thus the outgoing lead is identified with the letter-number designation of the connector in which that lead terminates J254-B. At this termination the lead is identified with the letter-number designation of the connector in which that lead originates (J253-L). This system facilitates servicing and trouble-shooting. Simplified schematics can easily be developed from this method of designating leads.

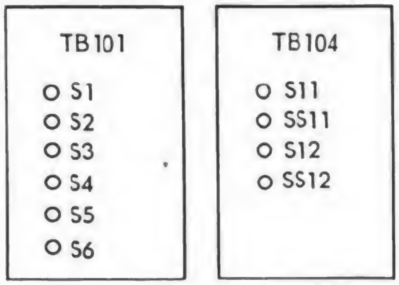
WIRING COLOR CODE FOR ELECTRONIC EQUIPMENT

To aid in testing and locating faults in electronic equipment, and in subsequent repair,

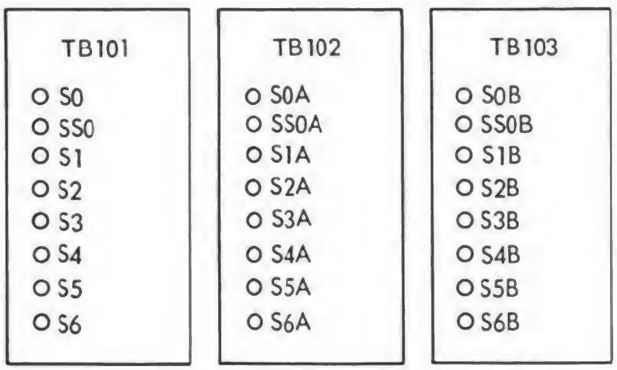


70.1

Figure 3-2. —Terminal board marking.



70.2
Figure 3-3.—Designations appearing beside terminals.



70.3
Figure 3-4.—Designating terminals of the same function.

the Department of Defense has set up a military standard (MIL-STD-122), which establishes a uniform wiring color code for all military electronic equipment. This standard is used in manufacturing and should also be followed in maintenance practices when circuit changes and part replacements are involved.

The standard colors used in chassis wiring are listed in table 3-7.

DESIGNATIONS FOR ATTENUATOR NETWORKS

Attenuator networks are illustrated in figure 3-8. They are used to attenuate signal voltages, and in many cases to effect an impedance match as well. The name of the network appears just above the schematic diagrams in the figure.

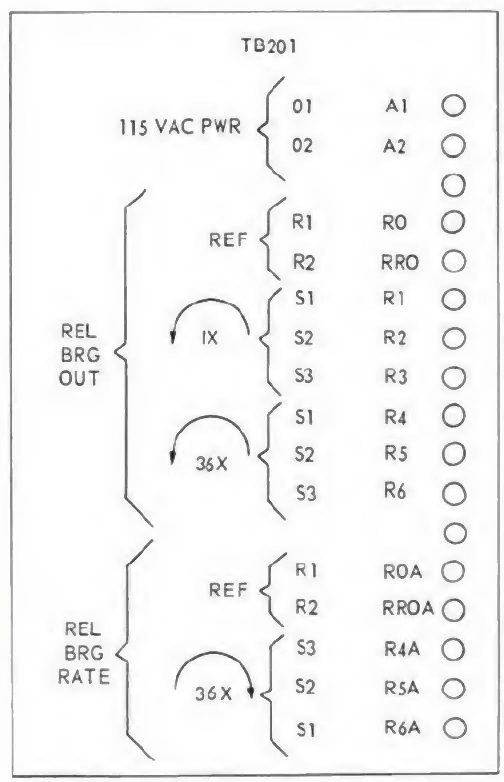
A BALANCED circuit is one in which both lines are at equal potential above ground. An UNBALANCED circuit is one in which one line is at ground potential.

MAINTENANCE RECORDS AND REPORTS

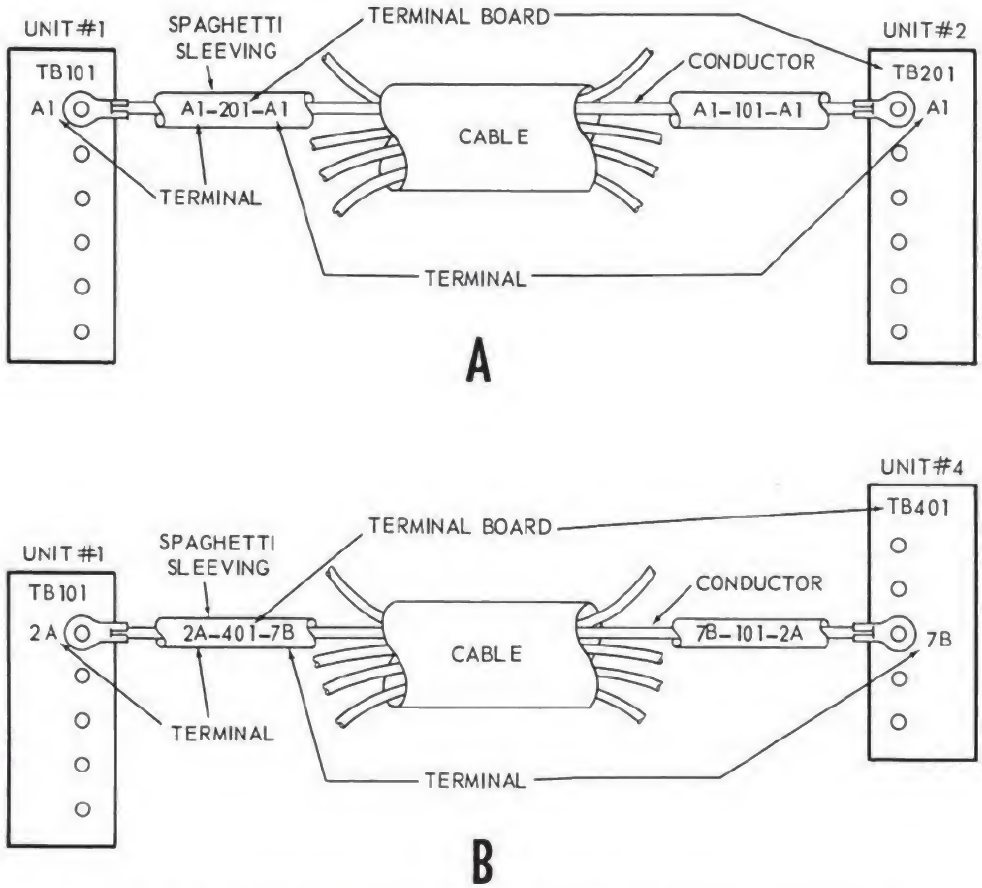
In addition to the manuals and instruction books already described, the CT M will need to be familiar with several standard Navy forms. The following section provides a description of the most important of these records or reports, including those used to record the history, maintenance, and failure of electronic material.

MATERIAL HISTORY

The Bureau of Ships Technical Manual, Chapter 9670, Electronics, states that each activity engaged in the operation of electronic



70.5
Figure 3-5. —Functional grouping of terminals, showing proper order within groups.



70.6

Figure 3-6. —Designating conductor marking between terminals.

equipment shall maintain suitable cards for recording the results of equipment inspections as well as any tests and field changes made. The purpose of these cards, when properly used, is to provide a comprehensive record of the equipment concerned. They will be kept current and available for inspection at all times and are the basis for the preventive maintenance program.

Electronic Equipment History Card (NavShips 536)

The Electronic Equipment History Card, NavShips 536, is the basic material history card for electronic equipment. It provides for recording failures and other pertinent information on electronic equipments. A separate card is made out for each unit on board. If additional cards are required they are added, and all cards for a particular unit are transferred with the unit when it is removed from the ship or station.

The heading of the card is so designed that when the card is properly filled in, all the necessary information is readily available for completing the upper part of the Electronic Failure Report (DD-787). The heading of the card should be typed, but entries on the body of the card may be either typed or written in ink or indelible pencil. The following instructions should be followed closely in filling in the form, a sample of which is shown in figure 3-9.

Equipment Model Designation: All letters and numbers should be included to indicate the specific model. For instance, AN/ARC-1 should NOT be entered as AN/ARC or ARC-1.

Equipment Serial Number: This refers to the main serial number of the equipment. Do not use the serial number of a unit or part. If in doubt, refer to the publication,

Reporting Electronic Equipment Installations, NavShips 900,135B, for location of main serial number. (NavShips 900,135B will soon be incorporated in the Electronics Installation and Maintenance Book.) Where it is definitely established that an item does not bear a serial number an asterisk (*) is entered in this space.

Card Number: The number in this space is number "1" for the first card on each unit of equipment in the original file. As additional cards for specific unit are filed, they are numbered consecutively.

Name of Contractor: Enter here the name of the contractor in full as given on the unit nameplate or in the technical manual.

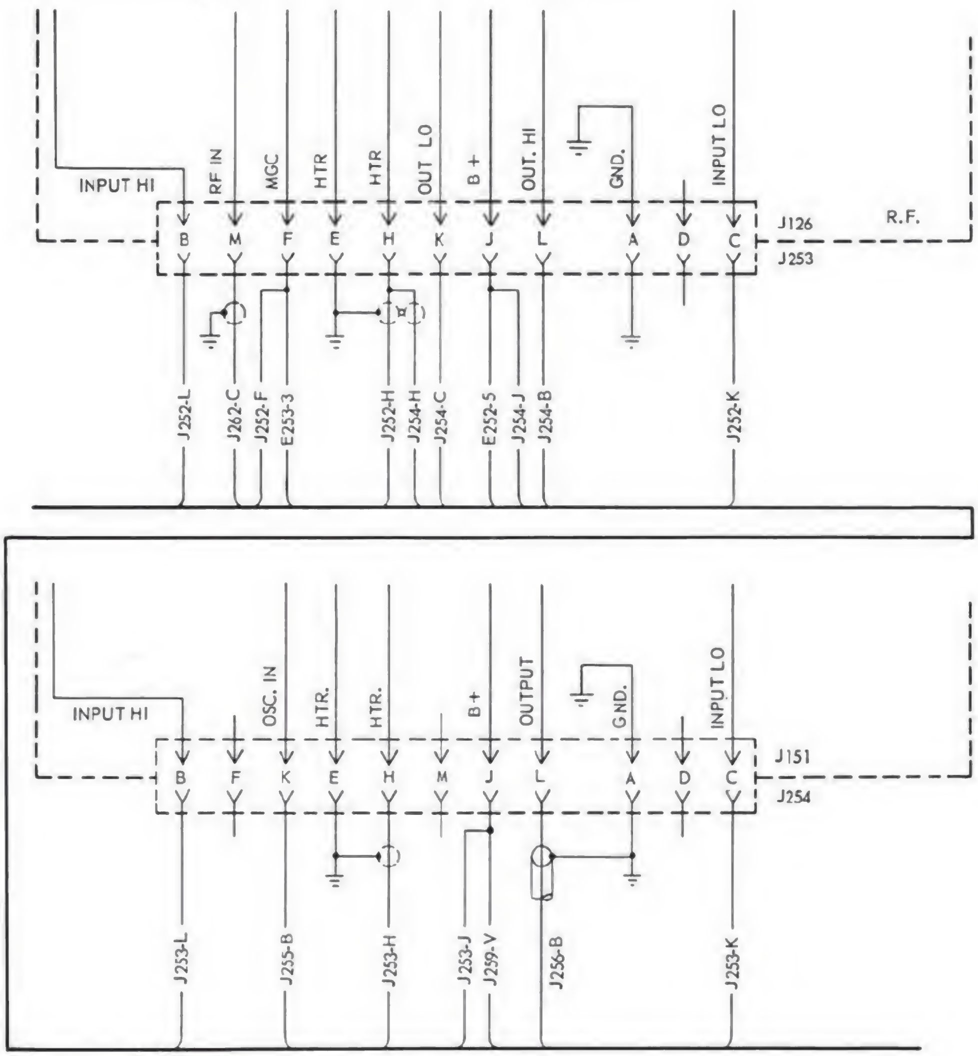
Contract Number: The complete contract number includes all contract letters and numbers as given on the unit nameplate.

Date Installed: This refers to the date the unit was installed. If the installation required several days, the date of completion is the date entered.

Serial Number of Unit: Enter here the serial number of the unit, taken from the unit nameplate. Do not confuse this number with the equipment serial number.

Location: Enter the name and designation of the space in which the unit is located. If the unit is portable, enter the space where it is normally stored.

Installing Activity: This space is for the name of the activity which actually installed the unit.



70.7

Figure 3-7. —Illustration of lead c

Table 3-7.—Wiring Color Code For Electronic Equipment.

Circuit	Color
Grounds, grounded elements, and returns	Black
Heaters or filaments, off ground	Brown
Power supply, B plus	Red
Screen grids	Orange
Cathodes	Yellow
Control grids	Green
Plates	Blue
Power supply, minus	Violet (purple)
A-c power lines	Gray
Miscellaneous, above or below ground returns, AVC, etc.	White

Box Number and Location: Enter here the numbers and locations of all boxes containing parts peculiar to the unit in question. If parts have been removed from boxes and stowed in bins, so indicate in this space.

Technical Manual on Board: This space is checked when the final technical manual (formerly instruction book) is received. If only the manuscript form of the manual is on board, the space should not be checked. To indicate the status of the edition that has been received (Manuscript, Preliminary, or Advance) it is recommended that the applicable abbreviation—MS, Pre, or Adv—be inserted here. Promulgating letters in manuscript-form manuals carry notices of the temporary status of these manuals.

Date: This refers to the date of a failure, the correction of a failure, the accomplishment of a field change, and other work involving maintenance or repair.

Nature of Trouble: External evidence of the equipment trouble is entered in this column. The action of the equipment which was symptomatic of trouble should be described in detail. Also, whenever a field change is made the field change number and title are shown in this column. This entry is in addition to the entry required on the Record of Field Changes (NavShips 537).

Cause of Failure: This column is most important. Describe how the trouble was traced and what corrective measures were taken. Give detailed information. Note peculiarities and weaknesses. The clearer the information in this column, the more valuable it will be to the station, the Bureau, and the manufacturer. It is also of value as a source of information for the technician in correcting similar future trouble. The information in this column, and that reported on the Electronic Failure Report (DD-787), assists in the production of better and more reliable equipment.

Some activities may wish to record in this column such information as the name and rate of the person actually doing or supervising the work, the man-hours consumed, and the signature of the division officer. Such entries are optional.

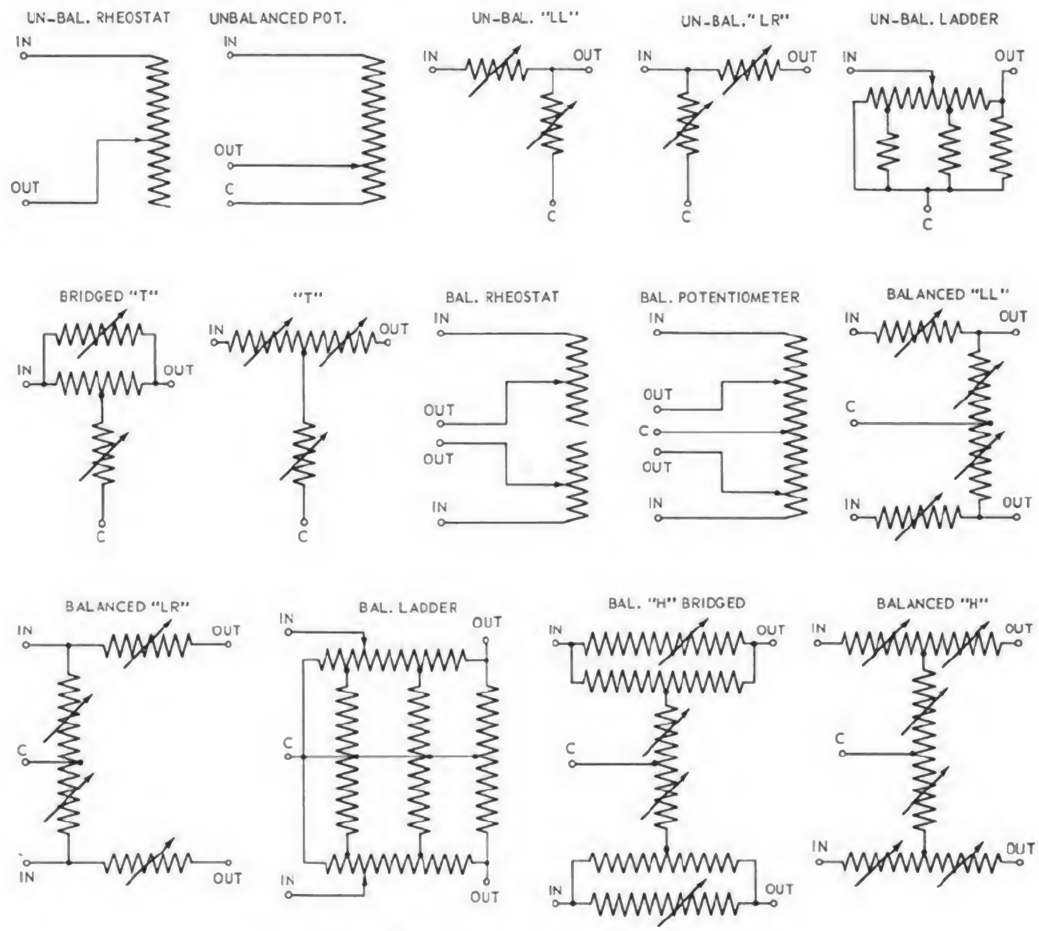
Name of Part: List here the names of the parts involved in the failure.

Circuit Symbol (Part Ref. Desig.): Record here the reference designations, as shown in the technical manual, of the parts that failed.

Navy Stock Number: This space is for the Federal stock number (formerly standard Navy stock number) including all prefix and suffix letters, exactly as given in the technical manual or Allowance Parts Lists (APL's).

Life Hours: Enter here the estimated life of the part. To obtain this figure use the machinery history cards, readings of elapsed time meters which total the operating time of the part, or any other available data.

Date DD-787 Mailed: Record the date the Electronic Failure Report (DD-787) was mailed to the Bureau. This means that all failures, including those of tubes, should be entered on the history card. The reason for this is that if, for example, the same type tube should fail several times in succession there would be reason to suspect that a circuit component is



70.8

Figure 3-8. —Attenuator networks.

causing an overload on the tube. With this clue supplied by the history card, the real cause of the failure can be ascertained.

Despite the shortage of CTs it is still possible to keep a complete material history by having each man who performs a repair make the entry in the material history as soon as he finishes the job. To ensure that proper entries are being made, the electronics officer should check them once a week for completeness and correctness. Spot checks should suffice to prove whether or not entries are being omitted. Large stations often require that repairs be logged in a workbook for checking by a supervisor who then enters them in the material history. This procedure is successful where there are many CTs; however, workbooks are not required by regulation. It is suggested that small stations log the repairs directly in the material history.

Resistance Test Record (NavShips 531-1)

The Resistance Test Record, NavShips 531-1, or megger card as it is commonly called, is shown in figure 3-10. It provides for recording the insulation resistance of units and circuits such as radio antennas and power distribution circuits. It is inserted in the material history binder with the applicable history card.

Resistance tests indicate when work is required to prevent expensive failures or to maintain equipment at its peak. Responsibility for resistance tests and record entries should be assigned to designated personnel who should be trained in the use of the megger and aware of the importance of accurate readings and entries. Because falling resistance readings may indicate the approach of trouble, the superivsor should check the records periodically. When a fall is noticed he should have

the reason determined and corrective action taken as necessary.

Electron Tube Performance Record (NavShips 538)

The Bureau of Ships no longer requires the use of the Electron Tube Performance Record, NavShips 538. The cards, however, may be used at the command's discretion for any large or expensive tubes for which it may be desirable to maintain separate records. When used, the cards are inserted in the binder behind the history card for the equipment in which the tube is installed. Upon failure of the tube, the card may be destroyed after an Electronic Failure Report (DD-787) has been completed and forwarded to the Bureau of Ships.

As a general rule, there is no life guarantee on MIL type tubes because each lot is accepted through a lot life test. In a limited number of cases, special type tubes are covered by a life guarantee. These may be identified by the life hour guarantee certificate which is shipped with the tube by the manufacturer. The life performance of these tubes should be recorded on this certificate by the user throughout the guarantee period. In case of failure during the gurantee period, the instructions contained on the certificate should be carefully followed.

If a ship or activity should, for no apparent reason, experience a series of premature failures of specific types of tubes, such information, along with a brief description of the failure conditions, should be forwarded immediately to the Bureau of Ships. Samples of the failed tubes should be retained by the activity until reply is received from the Bureau. Since failed tubes may convery valuable information to the manufacturer, their return for examination may be requested.

If, for information purposes, it is necessary or desirable for the Bureau to receive service life or performance data on new tubes or tubes of specific types, such information will be requested by special correspondence with the ships or activities operating equipment containing such tubes.

NAVSHIPS 536 (Rev. 9-48) ELECTRONIC EQUIPMENT HISTORY CARD

Stocked in CDS

R-390/URR	346	Radio Receiver	1
Equipment Model Designation	Equip. Ser. No.	Name of Unit and Type No.	Card No.

Name of Contractor	Contract No.	Date Installed	Serial No. of Unit
Collins Radio Company, Cedar Rapids, Iowa	NO bsr 56734	1/15/62	

Location Operations, Bldg. #4, Rm 102 — Installing Activity NAVCOMSTA, Guam

Spare Parts — Box No. and Location — Instr. Bk. On Board (Check) [X]

Date	Nature of Trouble (Or F. C. No. and Title)	Cause of Failure Brief Description of Work Done	Name of Part	Circuit Symbol	Navy Stock No.	Life Hours	Date 787 Mailed
6/2/62	No Signals	Open secondary winding	I F	T-207		600	
6/3/62		Replaced T-207			N5950-H-		6/4/62
					4321		
1/2/63	F.C. #1	As directed in		V-106	N5960-22		
	R-390/URR	Field change			4642	1100	
	Substitution	Bulletin-Corrections					
	for V-106	entered in Technical					
		Manuals					

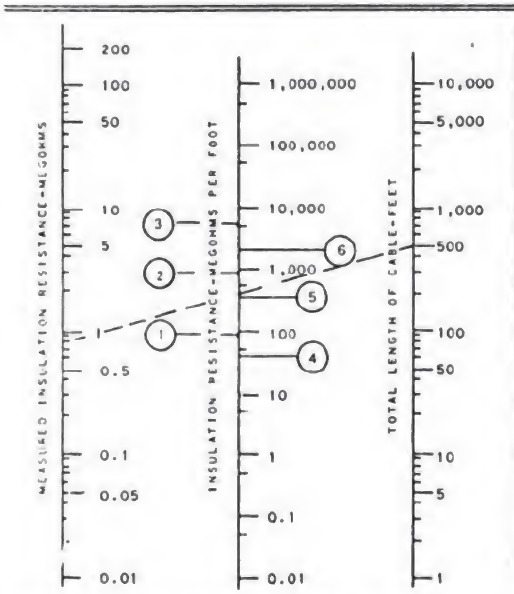
16-52956-1

1.2

Figure 3-9.—Electronic Equipment History Card (NavShips 536).

INDEX	CIRCUIT				LENGTH	CARD NO.
DATE (MO, DA, YR)	MEASURED RE-SISTANCE MEGS.	RESISTANCE PER FOOT (CABLE) MEGOHMS	AMBIENT TEMP. ASSUMED (104°F), 70°F, OR 40°F)	REMARKS		
	A					
	B					
	C					
	A					
	B					
	C					
	A					
	B					
	C					
	A					
	B					
	C					
	A					
	B					
	C					
	A					
	B					
	C					
	A					
	B					
	C					
	A					
	B					
	C					

RESISTANCE TEST RECORD CARD NAVSHIPS 531-1 (10-63) (FRONT)



NOMOGRAPH FOR OBTAINING RESISTANCE PER. FT.

OBTAINING RESISTANCE PER FOOT - *Example*

Line is drawn on nomograph from 0.8 megohms (measured) to 500 feet (length of cable per card or plans). If points 1, 4, or 5 apply, cable is O.K. If points 2, 3, or 6 apply, cable may be in poor condition - investigate further.

MINIMUM ALLOWABLE INSULATION RESISTANCE CABLES (MEGOHMS/FT)

	TYPE OF CABLE	
	SGA, HF, DG, SCA	TTHFA, TTHFWA
JUST AFTER SHUTDOWN 104°F	95 (POINT 1)	40 (POINT 4)
↓ EQUIPMENT SECURED 4 OR MORE HOURS		
WARM CLIMATE SUMMER OR ALL IN HEATED SPACE 70°F	920 (POINT 2)	380 (POINT 5)
COLD CLIMATE WINTER OR AGAINST COLD HULL 40°F	5500 (POINT 3)	2200 (POINT 6)

RESISTANCE TEST RECORD CARD NAVSHIPS 531-1 (10-63) (REVERSE)

1-23904

1.3

Figure 3-10. —Resistance Test Record Card (NavShips 531-1).

Record of Field Changes (NavShips 537)

Information on field changes for electronic equipment is recorded on the Record of Field Changes (NavShips 537). One of these cards is prepared for each equipment and filed in the material history binder with the history card for the equipment.

This record is of paramount importance. Without modifications an equipment may be dangerously out of date and subject to numerous serious difficulties. Without a record of field changes it is difficult to determine what modifications, if any, have been made. The information recorded on these cards is essential therefore for routine maintenance, for trouble shooting, and for ordering repair parts which belong to the improved equipment.

Figure 3-11 shows a Record of Field Changes (NavShips 537). The spaces for equipment model designation, serial number, date installed, and card number are filled out by typing or writing with ink or indelible pencil. The official name and Navy type number (or other official identification) of each component affected by a field change should be shown parenthetically after the title of a change.

The columns headed Number, Title of Field Change, and Authority for Change are to be completed in numerical order for all changes affecting a specific equipment. Field changes affecting given equipments are listed in the Electronics Installation and Maintenance Book (NavShips 900, 000) which indicates the instruction bulletin or reference instruction authorizing the change. The authorizing document provides information required in the above columns.

The columns, Change Made By and Date of Change, should be left blank until the change is completed at which time the name of the person making the change and the date should be entered. If the change applies to the model but not to the particular serial number of the equipment, the words, "not applicable," should be entered in these columns.

New field changes are listed in the Electronics Information Bulletin (EIB) which also gives the information needed to order the applicable field change kit, or, if a kit is not required, to order the field change bulletin. Kits are ordered on form DD-1145. If printed matter only is required, it is ordered on form DD-1149. Both were formerly ordered on S. and A. Form 43.

When the EIB lists a field change that is applicable to the equipment on board, the required material should be ordered and the change number, title, and authority should be entered on the Record of Field Changes.

ELECTRONIC EQUIPMENT FAILURE/REPLACEMENT REPORT DD-787

An Electronic Equipment Failure/Replacement Report, shown in figure 3-12, must be completed for every repair action that involves the failure or replacement of electronic, electrical, or mechanical parts, units, or assemblies in the equipments for which these reports are required. The list of electronic equipments for which these reports are required will appear periodically in Electronics Information Bulletin (NavShips 900, 022A). These are the only equipments for which these reports are required. In addition, this form is required to be completed for items found defective upon removal from supplies of spare items (stock defectives). These requirements apply equally to ships, Naval Shipyards, electronic shops, or any other facility utilizing or repairing Bureau of Ships electronic equipment.

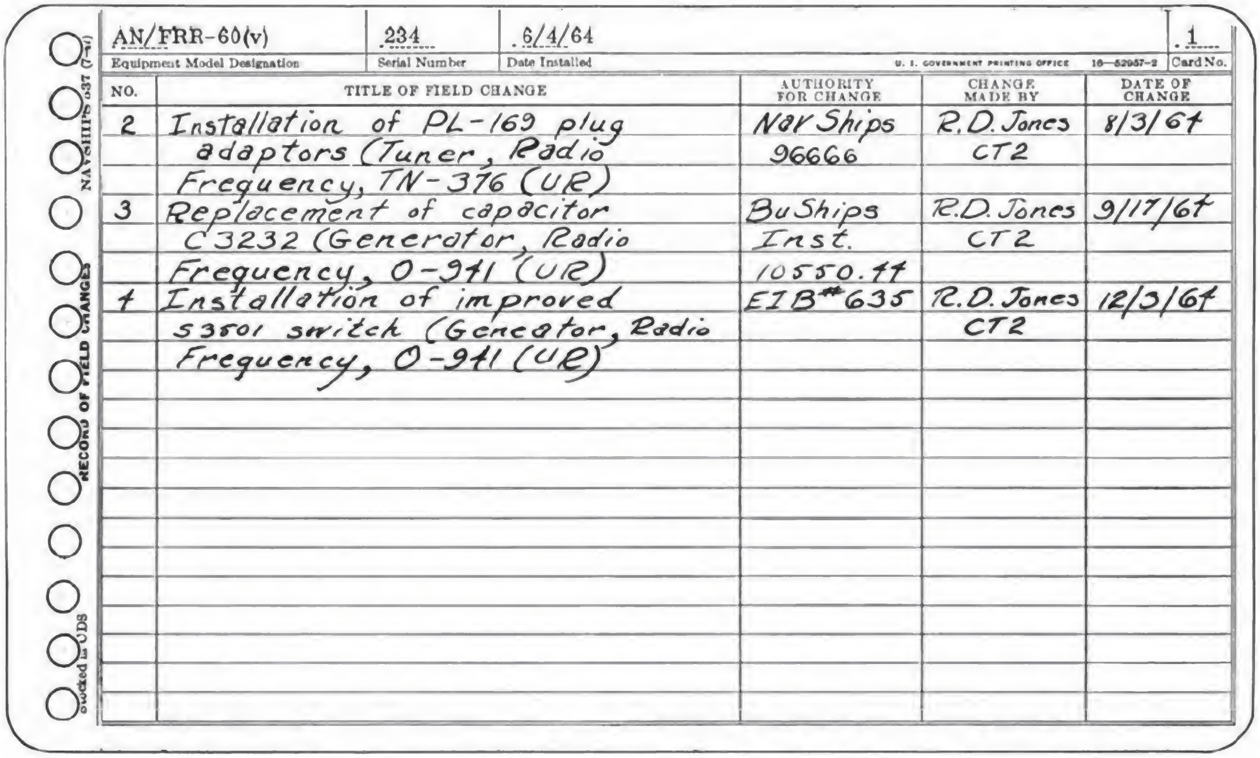
It is the responsibility of the technician who makes a replacement (part, unit or assembly) or discovers a stock defective item, to complete and submit a report form.

The report forms may be completed accurately by following the instructions appearing on the cover of the pad.

Electronic Equipment Failure/Replacement Reports are designed to provide the Bureau of Ships with information that is used for the following purposes:

1. Correcting deficiencies on either an equipment or part basis (e.g., field changes)
2. Evaluating equipment reliability and maintainability
3. Guidance for initial provisioning and reprovisioning of replaceable items
4. Stock control of replaceable items
5. Invoking contractual guarantees
6. Quality control in current and subsequent production.

The completed reports should be mailed promptly to the Chief, Bureau of Ships, Department of the Navy, Washington 25, D. C. Do not save them for periodic mailing. Submit only the white report form (top form of set) to the Bureau. The pink copy of the form set



AN/FRR-60(v) Equipment Model Designation	234 Serial Number	6/4/64 Date Installed		1 Card No.
NO.	**TITLE OF FIELD CHANGE**	**AUTHORITY FOR CHANGE**	**CHANGE MADE BY**	**DATE OF CHANGE**
2	Installation of PL-169 plug adaptors (Tuner, Radio Frequency, TN-376 (UR)	NavShips 96666	R.D. Jones CT2	8/3/64
3	Replacement of capacitor C3232 (Generator, Radio Frequency, 0-941 (UR)	BuShips Inst. 10550.44	R.D. Jones CT2	9/17/64
4	Installation of improved S3501 switch (Generator, Radio Frequency, 0-941 (UR)	EIB #635	R.D. Jones CT2	12/3/64

1.4

Figure 3-11.—Record of Field Changes (NavShips 537).

may be retained by the originator. When items are to be forwarded to another activity for repair or analysis, the yellow copy must be packaged with those items. The purpose of forwarding this yellow copy to the other activity is to provide personnel there with some background information concerning the failure or replacement of the item. A cover letter is not required unless the technician decides that an explanatory letter is necessary to discuss circumstances surrounding a failure or to make recommendations for correcting the deficiency found. Send sketches or photographs of failures when they are considered necessary. Ordinarily, the "Remarks" section of the report form should be used for explanatory comments.

Results of analysis of accumulated data will be presented in issues of the Electronics Information Bulletin from time to time. Diligence in providing accurate and complete data will assist in these analyses.

The form DD-787 carries no security classification. Classified military information, including in some cases the operating frequency, is therefore not to be included on the completed form.

All parts and electron tubes received by a ship, station, or other using activity should be examined immediately upon receipt for obvious breakage, defective packing, or signs of rough handling. All large or expensive tubes should be checked upon receipt for filament continuity, shorted elements, and loss of vacuum, and, when possible, they should be checked in an equipment socket under rated operating conditions. Failure reports should then be completed and forwarded to the Bureau for all parts and tubes received in defective condition. In addition, the supply activity from which the defective material was received should be notified promptly in order that the activity may initiate appropriate action in conformity with instructions in the Bureau of Supplies and Accounts Manual and the U.S. Navy Shipping Guide. Information copies of correspondence concerning

shipping claims are to be forwarded to the Bureau of Ships.

ELECTRONIC MATERIAL GUARANTEES

An additional and important purpose served by reports of failures is the supplying of information for use in enforcing guarantees on electronic material. When purchasing electronic equipment, it is the practice of the Bureau of Ships in most cases to include in the contract for complete sets a guarantee covering design, material, and manufacturer of each set and the components and parts thereof (except batteries, rubber, and material normally consumed in operation). This is also the general practice for electron tubes and piezo-electric quartz crystals which are covered by separate contract with the tube and crystal manufacturer respectively.

In recent contracts the practice has been to require a 1-year guarantee which becomes effective upon the date of acceptance by the Inspector of Naval Material. This date of acceptance, when available, and the date of installation should be entered by the installing activity in the appropriate logs, installation records, and equipment history card. Specified guarantee periods are automatically extended by whatever time the equipment fails to give the required performance because of any defect covered by the guarantee or lack of suitable replacement parts due to such defects.

To obtain maximum protection and effectiveness under terms of contractual guarantees it is essential that all failures be reported promptly to the Bureau of Ships. The information forwarded should be complete and so described that the Bureau can conduct an analysis which will provide a basis for claim under the applicable guarantee. (System and unit defects and failures are reported to the Bureau on Electronics Performance and Operational Report, NavShips 3878. Other defects and failures

ELECTRONIC EQUIPMENT FAILURE/REPLACEMENT REPORT DD-787 REPORT BUSHIPS 10550-1

1. DESIGNATION OF SHIP OR STATION: NSS, Washington, D.C.

2. REPAIRED OR REPORTED BY

NAME	RATE	AFFILIATION
Jones, R.D.	CT3	1. [X] U.S. NAVY 2. [ ] CONTRACTOR 3. [ ] CIVIL SERVICE

3. TYPE OF REPORT (CHECK ONE)
1. [ ] OPERATIONAL FAILURE
2. [ ] PREVENTIVE MAINTENANCE (POMSEE)
3. [X] PREVENTIVE MAINTENANCE (NOT POMSEE)
4. [ ] STOCK DEFECTIVE
5. [ ] REPAIR OF REPLACEABLE UNIT OR PLUG-IN ASSEMBLY
6. [ ] OTHER

	MONTH	DAY	YEAR	TIME
4. TIME FAIL. OCCURRED OR MAINT. BEGAN	April	21	64	0830
5. TIME FAIL. CLEARED OR MAINT. COMPL.	April	21	64	0835

EQUIPMENT

6. MODEL TYPE DESIGNATION: KWT-26C

7. EQUIP. SERIAL NO.: 642

8. CONTRACTOR (NAVY CODE OR COMPLETE NAME): Burroughs

9. FIRST INDICATION OF TROUBLE (CHECK ONE)
1. [ ] INOPERATIVE
2. [ ] OUT OF TOLERANCE, LOW
3. [ ] OUT OF TOLERANCE, HIGH
4. [ ] INTERMITTENT OPERATION
5. [ ] UNSTABLE OPERATION
6. [ ] NOISE OR VIBRATION
7. [ ] OVERHEATING
8. [X] VISUAL DEFECT
9. [ ] OTHER, EXPLAIN

10. OPERATIONAL CONDITION (CHECK ONE)
1. [ ] OUT OF SERVICE
2. [ ] OPERATING AT REDUCED CAPABILITY
3. [X] UNAFFECTED

11. TIME METER READING
A. HIGH VOLTAGE:
B. FILAMENT /ELAPSED:

12. REPAIR TIME: MAN-HOURS 0 TENTHS 1

REPLACEMENT DATA

13. LOWEST DESIGNATED UNIT (U) or SUB-ASSEMBLY (SA)	14 LOWEST DES. U/SA SERIAL NO.	15. REFERENCE DESIGNATION (V-101, C-14, R11, ETC.)	16. FEDERAL STOCK NUMBER	17. MFR. OF REMOVED ITEM	18. TYPE OF FAILURE	19. PRIMARY OR SECONDARY FAIL?	20. CAUSE OF FAILURE	21. DISPOSITION OF REMOVED ITEM	22. REPL. AVAILABLE LOCALLY?
KWP-26C		V9	N5960-577-3027	Sylvania	003	P [ ] S [ ]	8	D	Y [X] N [ ]
						P [ ] S [ ]			Y [ ] N [ ]
						P [ ] S [ ]			Y [ ] N [ ]
						P [ ] S [ ]			Y [ ] N [ ]
						P [ ] S [ ]			Y [ ] N [ ]

23. REPAIR TIME FACTORS								24. REMARKS
CODE	DAYS	HOURS	TENTHS	CODE	DAYS	HOURS	TENTHS	(CONTINUE ON REVERSE SIDE IF NECESSARY)

1.5

Figure 3-12. —Electronic Equipment Failure/Replacement Report DD-787.

are reported on the Electronic Failure Report, DD-787.) The activity reporting the defect or failure may be requested to furnish additional information to enable the Bureau to pursue claims under contractual guarantees. The Bureau will provide instructions requiring such information after analyzing the defects reported.

Upon determining that a claim is warranted, the Bureau advises the contractor and the cognizant Inspector of Naval Material (INM), since the INM is directly concerned with enforcing guarantees and obtaining suitable adjustments. When he receives this information from the Bureau, the Inspector of Naval Material takes the action necessary to obtain an appropriate adjustment under the terms of the guarantee.

Since guarantees apply to replacements for parts, units, and sets, as well as to the originals, these replacements must receive the same consideration as the original items with regard to recording dates of acceptance and periods of service and the prompt reporting of failures and defects.

SUPPLY SYSTEM

ELECTRONIC REPAIR PARTS SYSTEM

In the past, certain shore activities of the Naval Communication System had large stocks of electronic repair parts and equipments in stowage which were not reflected in the stock records of the activities' Supply Offices. To alleviate this problem and to better utilize the maintenance and operation funds, the Electronic Ready Supply Stores were established. These local supply stores are under the supervision of the Electronics Supply Office (ESO) which is located at Great Lakes, Illinois. This serves as an aid to the shore activity in the processing of Allowance Parts Lists, and the proper stocking of all electronic parts listed in the Electronics Repair Parts Allowance List.

Identification of Equipment Replacement Parts

In order for you to correctly identify the equipment replacement parts as listed in the repair parts lists, it is necessary for you to become familiar with a few basic terms. Terms which will be found in the basic repair parts lists are discussed in the following paragraphs.

FEDERAL STOCK NUMBER.—Federal Stock Numbers (FSN's) are assigned by the Department of Defense for use by all military services at all levels of supply. All Federal Stock Numbers are uniform in format and length. The applicable FSN is the most important single identification information on any item.

The Federal Stock Number uniformly consists of 11 digits. Take, for example, Federal Stock Number 5110-288-8723. The first two digits (51) of the four-digit classification, 5110, identify the broad GROUP of material—in this case, HAND TOOLS. The second two digits, taken in conjunction with the first two, indicate the CLASS within the group. In this case, Class 5110 means hand tools, EDGED, NONPOWERED. The remaining digits (288-8723) are the Federal Item Identification Number, used to complete the identification of the item—in this case, WIRE STRIPPERS. To facilitate reading, the FSN is always written with a dash after the fourth and seven digits.

In order to adapt the FSN to use in the Navy Supply System, cognizance symbols will be used to prefix the stock number. Condition codes and other special designations also will be used as required. Various cognizance symbols indicate types of material controlled by specific control points, bureaus, offices, or agencies. For example, Federal Stock Number 5110-288-8723 is adapted to the Navy Supply System as 9G5110-288-8723. The cognizance symbol "9G" indicates that the item is a retail, defense, general supply center item. A "2F" would indicate BuShips controlled items of major electronic equipment, and a "1N" would indicate Electronics Supply Office controlled items of electronic repair parts or assemblies.

CIRCUIT SYMBOLS.—Circuit symbols identify components in the equipment. Each component or part in an equipment has a circuit symbol number. This number appears on the schematic diagram of the equipment next to the part which it designates.

APPLICATIONS AND QUANTITY.—The term "applications" refers to the number of times this part is used in each individual set of equipment. Quantity refers to the recommended number of repair parts and/or tubes considered necessary to support one equipment model. Allowance = Qty X Nr. of sets.

REFERENCE NUMBERS.—Reference numbers are assigned by the manufacturer for their part, as shown in the manufacturer's instruction books of the individual set of equipment.

MANUFACTURER'S FEDERAL CODE NUMBER.—Manufacturer's Federal Code Numbers are designators assigned to the manufacturers of Department of Defense equipment.

Shore Plant Electronic Equipment List

The Electronics Supply Office will annually forward two copies of the Preliminary Shore Plant Electronic Equipment List to customer activities. The Preliminary SPEEL will contain a list of the electronic equipment at the customer activity according to the records at ESO.

Upon receipt of a Preliminary SPEEL, customer activities will verify the electronic equipment listed therein against a physical inventory to insure that the list contains all on-board electronic equipment as defined in ESO INSTRUCTION, P4441 series. After the verification of the Preliminary SPEEL each activity will return to ESO within 30 days of the date on the Preliminary SPEEL one marked-up copy of the verified Preliminary SPEEL. The goal to be attained is the establishment of equipment inventory records at ESO which will permit the determination of electronic repair parts to be positioned at stock points to maintain the command equipment in operative condition. Failure to report an equipment may result in excessive inoperative status due to lack of repair parts. Reporting equipment no longer on board will result in the needless expenditure of manpower and funds in positioning repair parts where they will not be required.

Upon receipt of the verified Preliminary SPEELs from each area, ESO will incorporate changes made by customer activities in its master EAM record of Shore Plant Electronic Equipment Inventories, and prepare and distribute:

a. A Shore Plant Electronic Equipment List (SPEEL) to each customer activity, copies of which will be distributed to the Bureau of Ships, appropriate management bureaus, and industrial managers or area commands.

b. Electronic Repair Parts Allowance Lists (ERPALs) to customer activities (1) who have reported changes sufficient to warrant preparation of a revised ERPAL or (2) once every two years.

Equipment Replacement Parts Lists

The Navy's electronic supplies and equipment allowance is under the supervision of the Electronic Supply Office, which originates a number of parts lists. Because some of these lists are commonly used by the CT M, you should become familiar with their contents.

ELECTRONICS REPAIR PARTS ALLOWANCE LIST.—The Electronics Repair Parts Allowance List (ERPAL) is a list of a station's allowed quantities of electronic repair parts. The list provides parts support for installed electronic equipments and indicates range and depth for the parts listed. The ERPAL takes into account the fact that every station has various types of equipment; some common parts may find application in more than one type of equipment. The parts that find common application in more than one type of equipment are called parts common, whereas those that are peculiar to just one type of equipment are called parts peculiar.

ALLOWANCE PARTS LIST.—Allowance Parts Lists (APLs) are parts lists for individual sets, produced in the same standard format for all electronic equipment. APLs serve a dual purpose. APLs are used to obtain the correct Federal Stock number for the replacement of a repair part in an individual set, and to identify parts in the repair part bins with a valid Federal Stock Number.

APLs contain the nomenclature symbol and all repair parts required to support the individual set. The APL is divided into three sections:

Section A, (see fig. 3-13), supplemental data, which provides a list of major units and circuit or reference symbol ranges, ESO-assigned symbols and applicable notes.

Section B (see figure 3-14) contains the circuit symbol cross-reference to the Federal Stock Number and part name.

Section C (see figure 3-15) is the allowance guide arranged in a Federal Stock Number sequence. The column order of this section is as follows:

(1) Item name

(2) Federal Stock Number (FSN)

ALLOWANCE PARTS LIST — SECTION A

SECTION A INDEX
1. Major Units

1. LIST OF MAJOR UNITS AND CIRCUIT SYMBOL RANGES WHICH ARE PART OF THE EQUIPMENT.

QUANTITY	TYPE NUMBER		UNIT NAME	SYMBOL RANGE AND/OR UNIT DESIGNATOR
	AN/UGC-6 c/o		Teletypewriter	
	Teletype Model	AN Nomenclature		
1	LAAC200BU	CY-2529/UG	Cabinet	
1	LAK4XY	MX-2643/UG	Keyboard	
1	LCXB-1	MT-2099/UG	Base Unit	
1	LESU12	SB-1061/UG	Panel, Power Distribution	
1	LESU13	SB-959/UG	Panel, Power Distribution	
1	LMU12	PD-67/U	Motor	
1	LMU3	PD-17A/U	Motor	
1	LPR9	TT-266/UG	Reperforator	
1	LP14RN	MX-1115B/UG	Typing Unit	
1	LRB6	MT-2234/UG	Base Unit	
1	LTPE1AWA	TT-252/UG	Perforator	
1	[illegible]	[illegible]	[illegible]	

1.6

Figure 3-13. —Section A of the APL.

ALLOWANCE PARTS LIST — SECTION B

UNIT	CIRCUIT SYMBOL	NOTES	FEDERAL STOCK NUMBER	SM&R CODE	ITEM NAME	UNIT	CIRCUIT SYMBOL	NOTES	FEDERAL STOCK NUMBER	SM&R CODE	ITEM NAME
	LAK4XY-154103			N FFC	STUD		LAJ4XY-155844		N5815-712-3085	P1FFC	KEYTOP
	LAK4XY-154105			N FFC	POST		LAK4XY-155951		N5815-712-3087	P1FFC	SPRING
	LAK4XY-154106			N FFC	BRACKET		LAK4XY-155952			N FFC	PIN
	LAK4XY-154109		N5815-675-6944	P1FFC	PLUNGER		LAK4XY-155953		N5815-767-9272	P1FFC	STUD
	LAK4XY-154110			N FFC	HOOD		LAK4XY-155954		N5815-652-2473	P1FFC	SWITCH
	LAK4XY-154111			N FFC	PLATE		LAK4XY-155955			N FCC	BAR
	LAK4XY-154115			N FFC	PLATE		LAK4XY-155956		N5815-652-1593	P1FFC	BAIL
	LAK4XY-154117		N5815-675-6946	P1FFC	BAIL		LAK4XY-155957		N5815-701-1654	P1FFC	BRACKET
	LAK4XY-154119			N FFC	BRACKET		LAK4XY-155958			N FFC	KEYLEVER
	LAK4XY-154120		N5815-652-1615	P1FFC	LEVER		LAK4XY-155959			N FFC	KEYTOP
	LAK4XY-154121		N5815-652-1616	P1FFC	LEVER		LAK4XY-155960		N5815-652-1594	P1FFC	LATCH
	LAK4XY-154122		N5815-652-1617	P1FFC	LEVER		LAK4XY-155961			N FFC	BUSHING
	LAK4XY-154123		N5815-652-1618	P1FFC	LEVER		LAK4XY-155962			N FFC	BUSHING
	LAK4XY-154124		N5815-652-1619	P1FFC	LEVER		LAK4XY-155963		N5815-767-3426	P1FFC	SHAFT
	LAK4XY-154125		N5815-652-1620	P1FFC	SPRING		LAK4XY-155964		N5815-652-1595	P1FFC	LEVER
	LAK4XY-154127		N5310-677-2280	P1FFC	NUT		LAK4XY-155965		N5815-652-1596	P1FFC	RACHET
	LAK4XY-154130		N5815-675-6992	P1FFC	BOX		LAK4XY-155966		[illegible]-652-1597	P1FFC	DRUM
	LAK4XY-[illegible]		[illegible]-675-6993	P1FFC			LAK4XY-[illegible]			P1FFC	WASHER

1.7

Figure 3-14. —Section B of the APL.

ALLOWANCE PARTS LIST — SECTION C							
ITEM NAME OR TUBE TYPE	STOCK NUMBER	APPL PER EQUIP	QTY	ITEM NAME OR TUBE TYPE	STOCK NUMBER	APPL PER EQUIP	QTY
BALL	G3110-100-6176	43	7	SWITCH	N5815-370-1354	1	1
BEARING	G3110-155-8418	6	2	BUSHING	N5815-370-0356	1	1
BEARING	G3110-155-9645	1	1	RACE	N5815-370-0473	4	1
BEARING	G3110-157-1909	1	1	WASHER	N5815-370-0776	18	1
RETAINER	G5340-205-4725	52	2	LINK	N5815-370-0812	2	1
RING	G5340-205-4731	34	3	SPRING	N5815-370-0827	11	3
RIBBON	G7510-526-1932	2	10	DISC	N5815-370-0937	8	1
SCREW	N5305-208-6403	22	4	DISC	N5815-3700938	2	1
SCREW	N5305-208-6409	1	1	DISC	N5815-370-0944	2	1
SCREW	N5305-298-2472	65	5	SHOE LEVER	N5815-370-1058	2	1
SCREW	N5305-370-0934	9	2	SHOE	N5815-370-1059	10	1
SCREW	N5305-639-3453	8	2	SHOE	N5815-370-1060	10	1
NUT	N5310-208-8716	125	16	LEVER	N5815-370-1063	5	1
WASHER	N5330-381-8823	3	1	ROPE	N5815-370-1116	1	1
	[illegible]-370-[illegible]	3	[illegible]	ROLL[illegible]	[illegible]-1117	1	[illegible]

1.8

Figure 3-15. —Section C of the APL.

(3) Applications per equipment
(4) Quantity allowed for one equipment installation.

Master Cross-Reference List

The Master Cross-Reference List (MCRL) includes reference numbers for all cognizance items of supply in the Electronic Segment of the Navy Supply System. There are three parts to the MCRL: Parts A, B, and C.

Part A, illustrated in figure 3-16 is a cross index of FSN to reference number and the Manufacturer's Federal Code.

Part B is a cross index from the reference number to the Federal Stock Number and the Manufacturer's Federal Code. (See figure 3-17.)

Part C (see figure 3-18) is a cross index for the reference number of an item to the FSN and the Manufacturer's Federal Code.

The main difference between part B and part C is that part C shows the complete reference number. It includes the manufacturer's part and type numbers, which, because of their length were not published in full in Part B. Part C contains the complete reference number in the same format and sequence as part B.

It should now be obvious that the MCRL is an important "tool" for locating the valid FSN from a reference number.

REQUISITION OF MATERIAL

A requisition is a request for materials or services. As a CT M you will need to obtain equipment replacement parts or maintenance supplies in order to perform your assigned duties. Therefore, it is necessary for you to know how to submit a correct supply form as well as use the repair parts lists in preparing the request. A request for the material is submitted on a Request for Issue or Turn-In (DD Form 1150).

To assist you in preparing the requisition, the following general information is offered. Since most stations will have different appropriation symbols, bureau control numbers, and so forth, no attempt is made at this time to explain them.

Request for Issue or Turn-In (DD Form 1150)

Requests for replacement parts or general stores material are prepared on a Request for Issue or Turn-in, DD Form 1150. Correct and complete information on the form is necessary for speedy and accurate action by the supply department, since issue of material for the Naval Security Group use is normally made by the local supply department. A sample DD Form 1150 is illustrated in figure 3-19.

NAVY STOCK LIST OF THE ELECTRONICS SUPPLY OFFICE

PART A

Class.	Federal Stock Number	Reference Number	Mfr. Federal Code	Class.	Federal Stock Number	Reference Number	Mfr. Federal Code
	N1210-202-2241	T3071872ALT8PT2	24446		N1280-311-7588	257-9555	46859
	N1210-202-2241	588485ALT8PT2	24446		N1280-311-7590	257-9552	46859
	N1210-321-6350	M4051138-2	24446		N1280-311-7593	257-9549	46859
	N1210-321-6350	ODC459116-2	80066		N1280-312-8943	41A42719	24009
	N1210-329-7687	BL47467	70408		N1285-201-4921	B033674-1	64959
	N1210-329-7687	BL47467	64959		N1285-548-9514	ES688892-7	64959
	N1210-381-9992	B554-134	72314		N1285-548-9514	ES688892-7	70408
	N1210-381-9992	486923	80066		N1290-324-1952	654026REVBP11	80066
	N1210-382-0162	1126-59	58336		N1325-311-9161	3K1-35	49956
	N1210-382-0162	607182	80066		N1430-342-5693	8106745	00000
	N1210-388-6531	B554-129	72314		N1430-342-5693	S4	37942
	N1210-388-6531	486918	80066		N1430-613-0107	194004481	87557
	N1220-319-4448	802788	53021		N1430-613-0122	194001209	87557
	N1220-319-4448	803901	53021		N1430-613-0123	1940F0366	87557
	N1220-321-6884	55207	80064		N1430-613-0124	1940F1416-2	87557

1.9

Figure 3-16.—Part A of the MCRL.

NAVY STOCK LIST OF THE ELECTRONICS SUPPLY OFFICE

PART B

Reference Number	Federal Stock Number	Mfr. Federal Code	Reference Number	Federal Stock Number	Mfr. Federal Code
BL45913	N5910-252-4111	70408	BL53028	N5840-387-4502	70408
BL45913	N5910-252-4111	64959	BL53028	N5840-387-4502	64959
BL46	N5960-295-3589	88236	BL53057ISSUE2	N5330-309-2668	64959
BL460097	N5840-303-4005	24446	BL53057ISSUE2	N5330-309-2668	70408
BL461813-119	N5995-198-6882	64959	BL53079ISSUE2	N5330-291-6579	64959
BL461813L2	N5995-198-6872	64959	BL53079ISSUE2	N5330-291-6579	70408
BL461813L2	N5995-198-6872	70408	BL53101	N5330-290-8613	64959
BL463348	N4130-387-6610	70408	BL53101	N5330-290-8613	70408
BL463348	N4130-387-6610	64959	BL53112	N3040-383-0505	64959
BL46692ISSUE4	N5950-648-1128	64959	BL53112	N3040-383-0505	70408
BL46692ISSUE4	N5950-648-1128	70408	BL53121ISSUE3	N3020-294-5298	64959
BL47466	N3020-699-3204	64959	BL53121ISSUE3	N3020-294-5298	70408
BL47466	N3020-699-3204	70408	BL53155	N5840-305-9559	70408
BL47467	N1210-329-7687	70408	BL53155	N5840-305-9559	64959
BL47467	N1210-329-7687	64959	BL53162ISSUE4	N5330-308-5237	70408
BL47509	N5940-332-4394	70408	BL53162ISSUE4	N5330-308-5237	64959
BL47509	N5940-332-4394	64959	BL53163REV3	N5985-295-8888	64959
BL47537	N5905-187-0022	24446	BL53190	N5985-382-7246	70408
BL48020	N3020-567-8724	70408	BL53190	N5985-382-7246	64959
BL48020	N3020-567-8724	64959	BL53196ISSUE3	N5985-319-4446	06679

1.10

Figure 3-17.—Part B of the MCRL.

NAVY STOCK LIST OF THE ELECTRONICS SUPPLY OFFICE

PART C

Reference Number	Federal Stock Number	Federal Code	Reference Number	Federal Stock Number	Federal Code
AA102436ISSUEAPT2	N5935-196-9692	86270	AM13UGHK3-5-115V60-5	N5925-606-7888	74193
AA102436ISSUEAPT2	N5935-241-7233	86270	ANBQR3AFIELDCHANGE1	N5845-568-7819	80058
AA102954ISSUEFPT1	N5935-666-1832	06845	ANBQR3FIELDCHANGE1	N5845-325-7506	80058
AA104757ISSUEAPT1	N5935-255-0951	86270	ANBQR4AFIELDCHANGE1	N5845-642-7905	80058
AA106046ISSUEBPT1	N5355-644-1950	06840	ANFFR49VSPECIALGROUPVWITH SPACEPART	N5950-588-6611	80058
AA110510ISSUEAPT1	N6210-295-2580	86270	ANGRC27FIELDCHANGE3	N5820-336-1664	80058
AA115575ISSUECPT2	N6625-699-1380	06845	ANGRC9FIELDCHANGEKIT1	N5820-642-6985	80058
AA117951SSUECPT1WA2953	N5935-642-3734	06845	ANPDR10AALUMINUMFOIL	N5935-294-6583	80058
ACAAB60000HMSPORM10PCT5W	N5905-174-8234	44655	ANSPA4AFIELDCHANGE	N5840-311-3278	80064
ACLOP500000HMSPORM10PCT	N5905-100-7959	44655	ANSPA8FIELDCHANGE2	N5840-311-3271	80058
ACYOU18000HMSPORM5PCT	N5905-542-8607	44655	ANSPA8FIELDCHANGE1	N5840-330-4876	80058
ACYOU2000HMSPORM1PCTLOW	N5905-642-3538	44655	ANSPS10FIELDCHANGE2	N5840-311-3297	80058
AC12072REVDITEM14	N5805-642-5849	42542	ANSPS12FIELDCHANGEKIT3	N5840-325-7474	80058
AC20K750000HM20WPORM5PCT	N5905-556-7036	12697	ASPS5BFIELDCHANGE3	N5840-311-3295	80058
AC480321PXISSUE2PT2	N5930-636-4644	76572	ANSPS6-6A6BFIELDCHANGE31	N5840-311-3283	80064

1.11

Figure 3-18. —Part C of the MCRL.

STOCK NUMBER AND DESCRIPTION OF MATERIAL AND/OR SERVICES.—In filling out this part of the Request you must enter the complete Federal Stock Number, the item's descriptive name, and any data that will assist the Supply Department to identify the item ordered. ONLY ONE line item (part) is ordered on the DD 1150.

PRIORITY.—All requests for material must be processed in accordance with the Uniform Issue Priority System and based on two factors: (1) a Force/Activity Designator, and (2) an Urgency of Need Designator.

The Force/Activity Designator establishes the relative military standing and importance of the mission of the station or ship, while the Urgency of Need Designator establishes the material requirement.

Since priority numbers must be assigned to all requisitions, and the Force/Activity Designator and the Urgency of Need Designator may change frequently, a conversion table, like the one shown in figure 3-20, must be consulted to determine the numeric priority to be assigned.

To determine the numeric priority, consult the conversion table for the Force/Activity Designator assigned. Read down the conversion table stopping at the appropriate Urgency of Need Designator. The number appearing here is the priority number that will be shown on your requisition in block 7. (figure 3-19).

REQUEST NUMBER.—When it has been determined that an issue is to be made and the supply requisition form is properly prepared, the requisition is assigned a number which is placed in block 5 of DD Form 1150. This number is the next consecutive number, in the series maintained separately by each activity or department, in the Stub Record Book.

AUTHORIZATION FOR REQUEST.—Before submitting the request to the supply department, the request is screened by your department head. Control of all issues is required, since departmental budgets can be exceeded

only by authorization of the commanding officer. Provided the department has unobligated money, the head of a department has the authority to order the following types of materials:

1. Consumable stock
2. Equipage or repair parts needed to fill allowances.
   a. Where material has been surveyed.
   b. Where full allowance has not been received.
   c. When a change in the allowance list has authorized more material.
3. Repair parts needed for immediate repairs.

Authorization for the issue is indicated in block 10 of the DD 1150, and is signed by the department head or his delegated representative.

INVENTORY

At small activities where no Supply Corps personnel are assigned, the job of maintaining a repair parts store will fall to the CT M. By keeping the repair part stock record cards up to date at all times, an accurate running account of stock on hand will be maintained.

The CT M may be called upon to assist the supply officer and department head in taking an inventory of Plant Account property. This inventory consists of checking the accuracy of the entries on the Plant Property Cards for agreement with equipment nomenclature, serial numbers, and location. CT Ms will assist in keeping the Electric Accounting Machine (EAM) Tabulation for equipment and electronic test equipment current by making additions, deletions and changes in employment.

REQUEST FOR ISSUE OR TURN-IN

ISSUE / TURN-IN	SHEET NO. 1	NO. OF SHEETS	5. REQUEST NUMBER N30/100/64		
1. FROM: N-30 (Lester x343)	6. DATE MATERIEL REQUIRED 14 July 64	7. PRIORITY 9			
2. TO: N-50	8. VOUCHER NUMBER	9. POSTED	DATE	BY	
3. APPROPRIATION SYMBOL AND SUBHEAD 1741804. 1115O&MN64	OBJECT CLASS 26	EXPENDITURE ACCOUNT (From)	(To) 44141	CHARGEABLE ACTIVITY 70092	BUREAU CONTROL ACTIVITY NUMBER 70092; BUREAU CONTROL NUMBER 51441; AMOUNT 2, 60; JOB ORDER AAC 430
4. END ITEM IDENTIFICATION	a. NAME AND MANUFACTURER	b. MODEL	c. SERIAL NUMBER	d. PUBLICATION	

ITEM NO. (a)	STOCK NUMBER AND DESCRIPTION OF MATERIEL AND/OR SERVICES (b)	* CODE (c)	UNIT OF ISSUE (d)	QUANTITY (e)	SUPPLY ACTION (f)	UNIT PRICE (g)	TOTAL COST (h)
	N5960-262-0210, Tube, 5814A		ea	2			
*ISSUE-I-Initial; R-Replacement	TURN-IN-U-Unserviceable; S-Serviceable				GRAND TOTAL		

10. ISSUE OR TURN-IN OF QUANTITIES IN "QUANTITY" COLUMN IS REQUESTED	DATE 24 June 64	BY P. R. FERREBEE	11. RECEIVED QUANTITIES IN "SUPPLY ACTION" COLUMN	DATE	BY

DD FORM 1 OCT 57 1150 (9 pt.) REPLACES EDITION OF 1 JUL 56 WHICH MAY BE USED.

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Figure 3-19.—Request for Issue or Turn-In (DD Form 1150).

END USE CODE

MISSION CATEGORY	A	X	B	C	D	E	F	G	H
1	1	3	5	11	17	20	22	30	37
2	2	3	8	12	18	21	23	31	37
3	4	3	9	13	19	24	25	32	37
4	6	3	10	15	26	28	33	35	37
5	7	3	14	16	27	29	34	36	37

1.13

Figure 3-20.—Mission category/end use conversion table with priority designators.

CHAPTER 4

THE USE OF HAND TOOLS IN ELECTRONICS

Skill in the use of hand tools comes only with experience. However, much valuable background information may be obtained from a study of the types, use, and care of the tools commonly used by Communications Technicians.

If a CT M is skilled he need not announce this fact; the method by which he selects, handles, and cares for hand tools does this for him. Good tools cost money, but there is something in the feel of a good tool that inspires a technician to turn out better work. This fact alone justifies the additional investment needed to obtain good tools. Of course, cheap tools become defective much more readily than quality tools. When quality tools are provided, it is only reasonable to give them quality care.

There are several safety measures that should be taken whenever the technician uses hand tools. One of the most important is—do not be in too big a hurry to get through; take enough time to be careful. Excessive hurry is dangerous, and it often results in poor-quality work. Other safety measures are (1) use a vise or clamp to hold the work when a drilling or cutting tool is used (avoid using the hand as a holding device); (2) use a guard over a grinding wheel, and goggles to protect the eyes during grinding operations; (3) when using a rest to grind parts or tools, place the rest close to the grinding wheel; (4) do not scatter tools around where someone can trip over them or where there is a chance of their falling on someone; (5) do not lay tools in or on equipment during the course of your work, replace them in the box or tool carrier when they are not actually in use; (6) carry an inventory list of tools in your tool box so that upon the completion of a job you can check to see that no tools are left in, on, or in the vicinity of the equipment; and (7) report all injuries promptly.

Some general precautions are (1) do not throw hardened steel tool files together because this will injure their cutting edges, (2) do not use a wrench as a hammer, (3) do not jam a piece of finished work in the jaws of a vise (use aluminum or copper jaws when needed), and (4) watch out for rust; it is the enemy of steel. Perspiration is corrosive; therefore, micrometers and gauges should be wiped clean after use and a thin coating of oil applied before they are put away.

The following treatment of the use of hand tools in electronics work is necessarily brief. Much could be said on the subject, but it certainly can be assumed that the CT M will have at least a general familiarity with the common tools of the trade.

Additional valuable information may be obtained from Chapter 3 (Hand Tools) of <u>Electronic Installation Practices Manual</u>, NavShips 900,171. Good general information (not tied specifically to electronics) on the use of hand tools is included in <u>Basic Hand Tools</u>, NavPers 10085-A.

Some of the information contained in this chapter is condensed from <u>Unit Course Mechanic Learner—Radio</u> put out jointly by the U.S. Army Signal Corps and the U.S. Office of Education, various issues of the <u>Bureau of Ships Journal</u>, and NavShips 900,171.

Table 4-1 lists the various hand tools commonly used in electronics work and gives the group number and part number where they may be found in the Navy Stock List of General Stores.

HAMMERS

Hammers are generally familiar to most people and need not be illustrated here. The

Table 4-1. —Group and Part Numbers Corresponding to Hand Tools Found in the Navy Stock List of General Stores.

	Group number	Part number
Soldering equipment	34	3
Hand drills	51	2
Circle cutter and chassis punches	51	2
Files	51	2
Hacksaws	51	2
Wire strippers.	51	2
Hammers	51	3
Screwdrivers.	51	3
Wrenches	51	3
Pliers	51	3
Punches	51	3
Crimping tools.	51	3
Fuse pullers	51	3
Portable electric drills . . .	51	4

general types are the claw hammer, the ball peen hammer, and the soft-faced hammer. The ball peen hammer is used for setting rivets, and the soft-faced hammer is used when work is done on soft metals or other surfaces that may be easily marred or dented. These hammers have faces of rawhide, plastic, copper, or lead. The regular claw hammer is generally familiar to everyone.

The hammer head should always be tight on the handle for safety reasons. When a hammer is used on a machined surface, the surface should always be protected with a piece of soft brass, copper, lead, or a hardwood block.

SCREWDRIVERS

Screwdrivers are designed to loosen or tighten screws. The three main parts of a Standard screwdriver are illustrated in figure 4-1A. This type of screwdriver is made in a variety of sizes and finds considerable use in electronics work. The handle may be wood or plastic.

The Heavy Duty screwdriver (fig. 4-1B) has a square shank. It is the only type of screwdriver designed so that it may be used with a wrench. The handle is not insulated.

Close-Quarter, or Stubby screwdrivers (fig. 4-1C) are used where space will not permit the use of a standard-size screwdriver.

The Phillips (Cross-Tip) screwdriver (fig. 4-1D) has a cross-tip blade that fits the two slots that cross at right angles to each other in the Phillips-head screw.

Self-Holding screwdrivers (fig. 4-1E) are so designed that they will hold small screws when it becomes necessary to start a screw in a limited space. The screw is "locked on" by means of a special holding device. When the screw is nearly in, the turning pressure releases the driver from the screwhead. A standard screwdriver is then used to tighten down the screw.

The Close-Quarter Combination flat tip and Phillips tip (fig. 4-1F) has the obvious advantage of fitting two types of screwheads.

Screwdriver Handle and Bit Sets (fig. 4-1G) are also available. The technician simply chooses the bit of the correct size and pushes it into the handle; he is then ready for business.

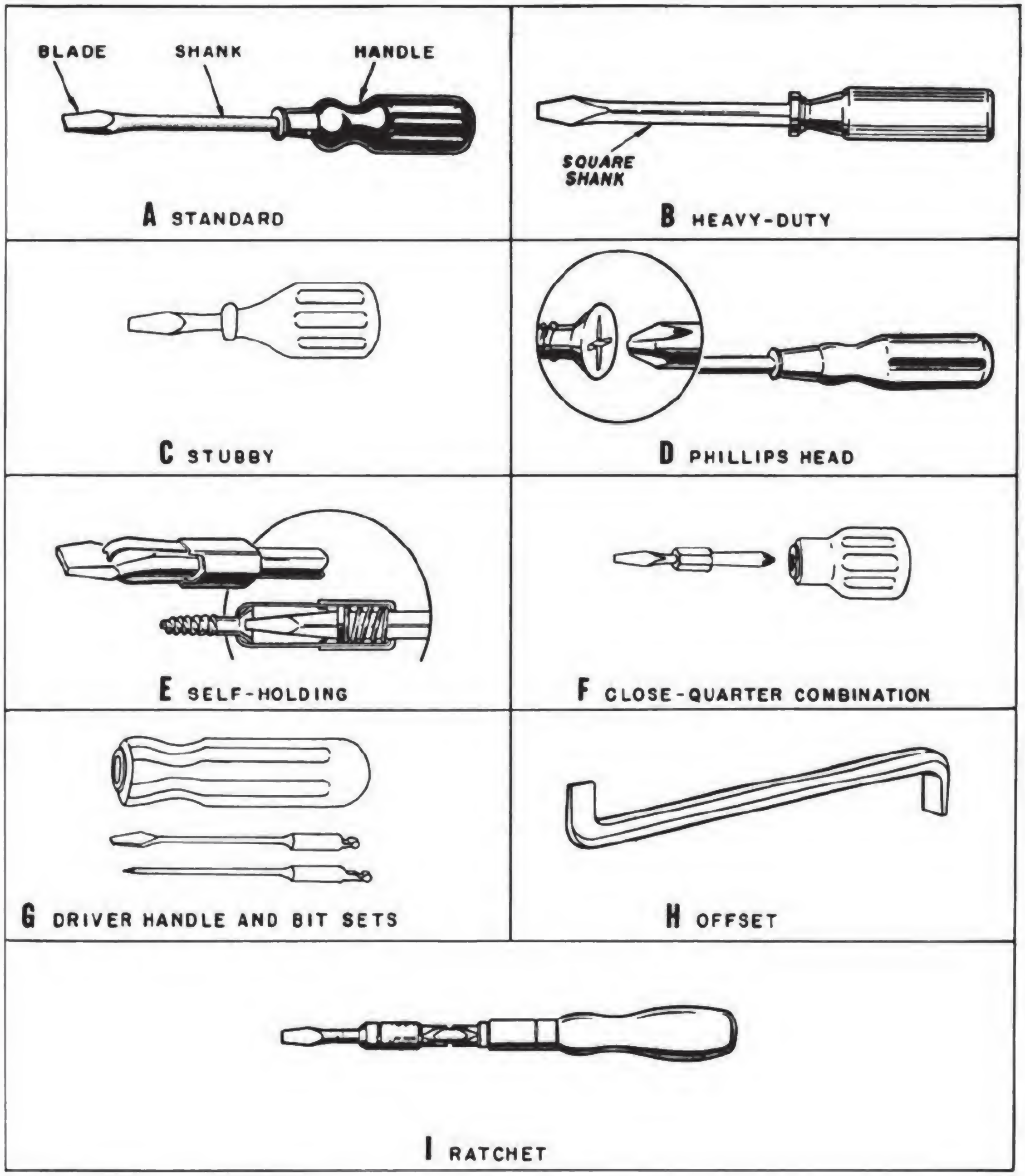
The Offset screwdriver (fig. 4-1H) is used where space will not permit the use of a standard-size screwdriver. It has one blade in line with the shank and one blade at right angles to it. When the working space is limited the wrench can be reversed after each swing to tighten or loosen the screw.

When many screws have to be put into a chassis, the Ratchet screwdriver (fig. 4-1I) is a great time saver because by pushing on the handle a twisting motion is created at the blade. Some makes have removable blades so that an assortment of blade sizes may be used, and a button to reverse the rotation of the blade.

It is important to select a screwdriver that will fit snugly into the screw slot. This will prevent the screw slot from becoming burred and the screwdriver blade from becoming damaged; also the force required to keep the screwdriver in the slot will be reduced.

If the blade of the screwdriver should become damaged, it may be restored to service by grinding. Of course, goggles should be worn whenever grinding is being done.

Figure 4-2A, illustrates a correctly ground blade. Part B illustrates an incorrectly ground blade. The first step in the correct procedure is to grind the end of the blade at a right angle to the shank. After the end of the blade is ground, each face is dressed off a little at a time. The faces are kept parallel for a short distance from the tip, or they may be tapered

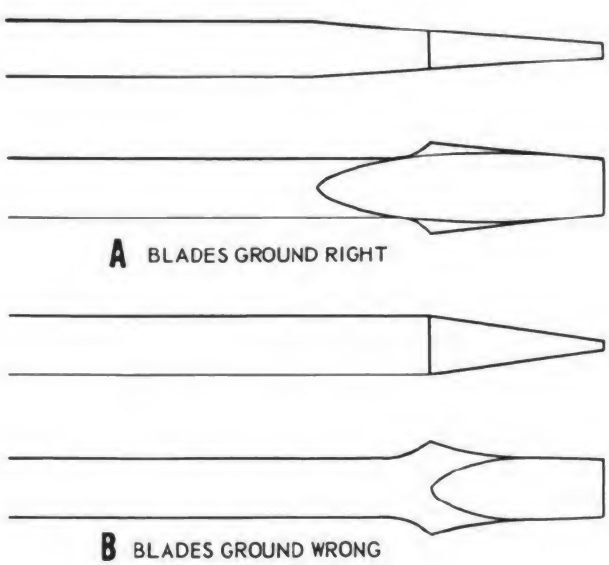


1.14

Figure 4-1.—Types of screwdrivers.

very slightly as shown in the figure. The faces should not be ground so that they taper to a sharp edge at the blade end.

The general care of a screwdriver consists largely of NOT doing certain things. Do not hammer on a screwdriver if something is obstructing the screw slot; instead, apply a driving force with the heel of the hand, or remove the obstruction some other way. Do not use a screwdriver as a pinch bar, lever, or



1.15

Figure 4-2.—Correctly and incorrectly ground screwdriver blades.

chisel. Never use a wrench on a screwdriver with a round shank, and do not use pliers on a screwdriver under any circumstances.

There are certain safety precautions involved in the use of the screwdriver. Never use a screwdriver to check an electrical circuit. Danger of severe burns, blindness, and even death can occur if the screwdriver is shorted across a high-potential or current-carrying source. However, screwdrivers having plastic handles may be used to discharge SMALL capacitors.

WRENCHES

Several types of wrenches are used in electronics work. They include: open-end, box, and combination wrenches; socket wrench sets and spin-type socket wrenches; adjustable wrenches; Allen and Bristol wrenches; spanner wrenches; monkey wrenches; and slugging wrenches.

Some of the more commonly used wrenches are illustrated in figure 4-3. Most of the wrenches illustrated in this figure come in sets having a range of sizes.

Open-End wrenches (fig. 4-3A) are solid nonadjustable wrenches with openings at each end. The smallest wrench in the average set has a 5/16-inch opening in one end and a 3/8-inch opening in the other. It is therefore called a 5/16 by 3/8 open-end wrench.

The openings actually measure from 5 to 15 thousandths of an inch larger than the sizes marked on the wrenches. This makes it easier to apply the wrench to a bolthead or nut.

The Box wrench (fig. 4-3B) derives its name from the fact that it completely surrounds the nut or bolthead. Modern box wrenches have 12 notches within the box circle and are referred to as 12-point type. These wrenches are popular because they do not slip off the nut or bolt when they are turned.

Combination wrenches (fig. 4-3C) are simply a combination of an open-end and a box wrench.

Socket wrenches (fig. 4-3D) come in sets. The sockets are usually of the removable type and are of 12-point design. A socket set will include a T-handle, ratchet handle, and a speed handle, plus one or two extension shanks. The speed handle resembles a carpenter's brace.

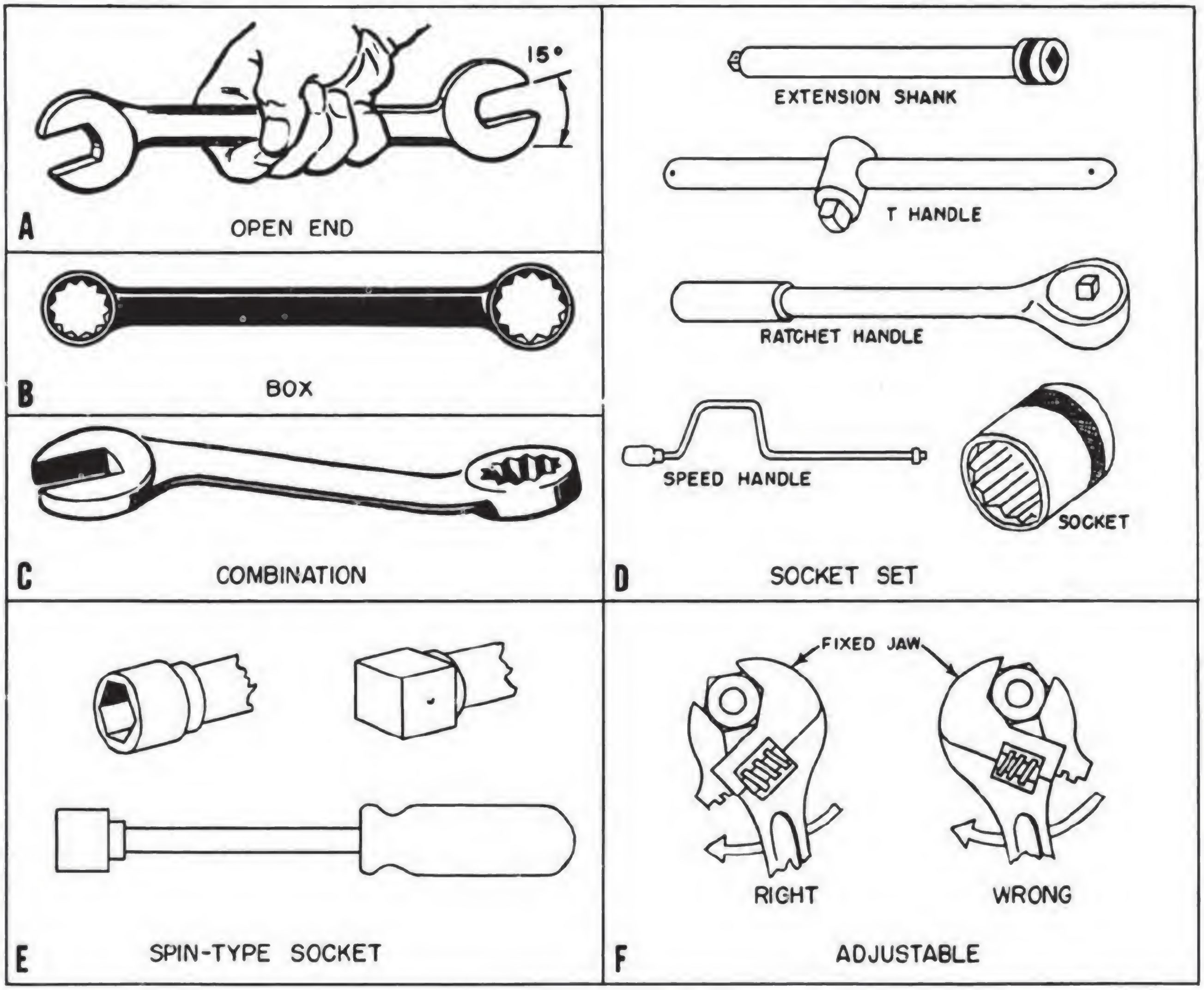
Spin-Type socket wrenches (fig. 4-3E) are very popular in electronics work. In some sets the socket is an integral part of the wrench; in other sets (like the one shown) sockets of various sizes may be attached to a common handle. To attach the socket to the handle, one simply pushes the socket in until the ball snap-on grip holds it in place.

Adjustable wrenches (fig. 4-3F) are not intented to replace the standard open-end wrench and are generally used in cases where only one wrench is needed to fit a variety of nut or bolt sizes. It should never be used at its widest opening because this is the weakest position and the jaws may be spread. The right and wrong methods of using this wrench are shown in the figure.

Other wrenches are illustrated in figure 4-4.

Allen, or hex, wrenches (fig. 4-4A) are designed to fit hexagonal socket setscrews. They are made of tool steel and bent in an L-shape and either end may be used.

Bristol wrenches (fig. 4-4B) are somewhat like Allen wrenches. They are fluted to fit into the special fluted Bristol setscrew. These wrenches are not standard stock items because manufacturers normally supply these special wrenches when they are required for their equipment.



1.16

Figure 4-3.—Common types of wrenches.

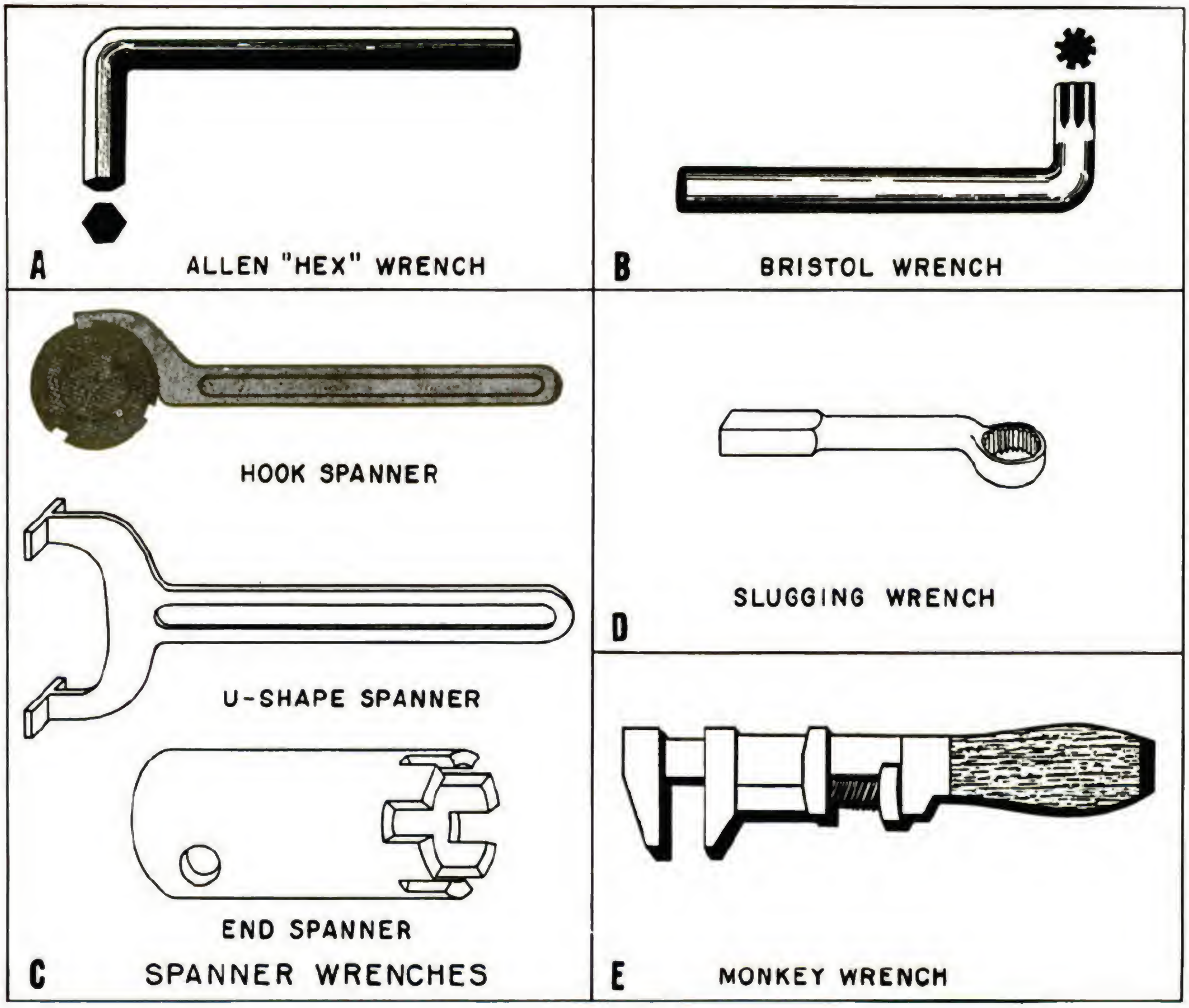
Spanner wrenches (fig. 4-4C) are special tools for special jobs. Three common types are shown in the figure. The hook spanner is used for rounded nuts that have a series of notches on the outer edge. The U-shaped hook spanner fits notches on the face of a nut or screw-plug. The end spanner wrench has a series of lugs on the end that fit into notches in the nut or plug.

Slugging wrenches (fig. 4-4D) are the only wrenches designed to be used with a hammer. Hammers should not be used with other wrenches.

Monkey wrenches (fig. 4-4E) require the same precautions in use as do adjustable wrenches (see right and wrong method of using the adjustable wrench).

PUNCHES

The center, starting, pin, aligning, and hollow-shank gasket punches are useful in electronics work. Punches are made of tool steel, tempered and hardened at the point. Punches should never be used on extremely hard metals or to remove bolts by force because the point will be dulled. Several types are illustrated in figure 4-5.



1.17

Figure 4-4.—Special types of wrenches.

The Center punch (fig. 4-5A) is used to make a punch mark for starting a drill. The point is carefully ground to an angle of 60°, which is the same as the angle of a standard twist drill. Drills will start quicker and have less tendency to wander if they are started in a punched hole.

The Starting punch (fig. 4-5B) is used to knock out rivets after the heads have been cut off. It is also used to start driving out straight and tapered pins because it can withstand the heavy hammer blows necessary to break loose the pin and start it moving. This punch is made with a long, gentle taper extending from the tip to the body of the punch.

The Pin punch (fig. 4-5C) is made with a straight shank and is used to follow up on the job requiring a starting punch. After a pin has been partially driven out with a starting punch, which is limited in use because of its increasing taper, the pin punch with its slim shank is used to finish the job.

Never use a pin punch as a starting punch because a hard blow may cause the slim shank to bend or break. Always use the largest size starting and pin punch that will fit into the

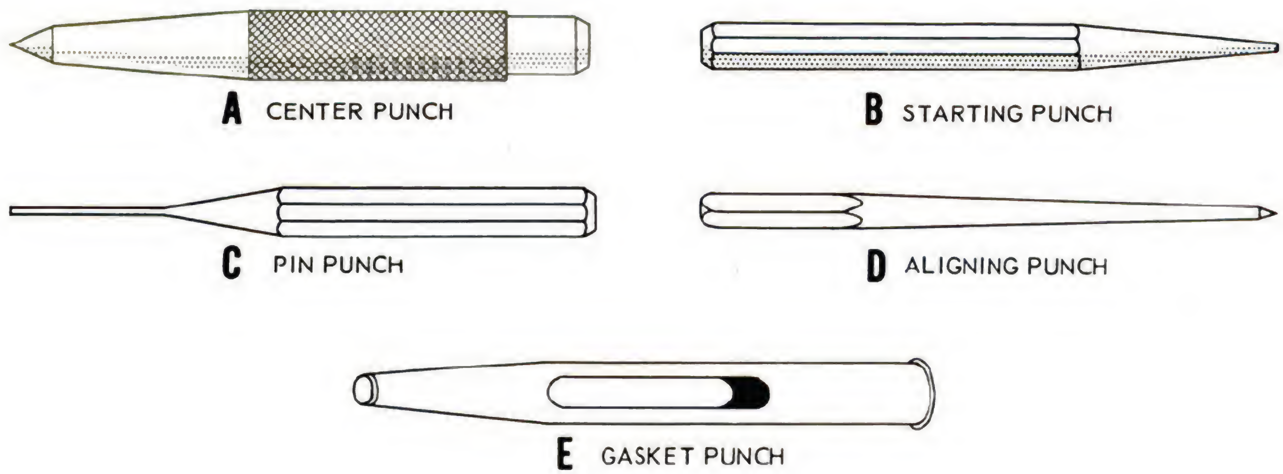


Figure 4-5.—Types of punches. 1.18

hole. Do not strike the pin punch with a glancing blow because the punch may be broken, and broken pin punches may be difficult to remove.

The Aligning punch (fig. 4-5D) is from 12 to 16 inches in length and has a long taper. This punch is used for moving or shifting plates or parts so that corresponding holes will line up. It should not be used for a pry bar.

The hollow-shank Gasket punch (fig. 4-5E) is used for cutting holes in gaskets and similar materials. The cutting end is tapered to a sharp cutting edge to make clean, uniform holes. The material to be cut should be placed on a soft background such as lead or hardwood so that the cutting edge will not be damaged.

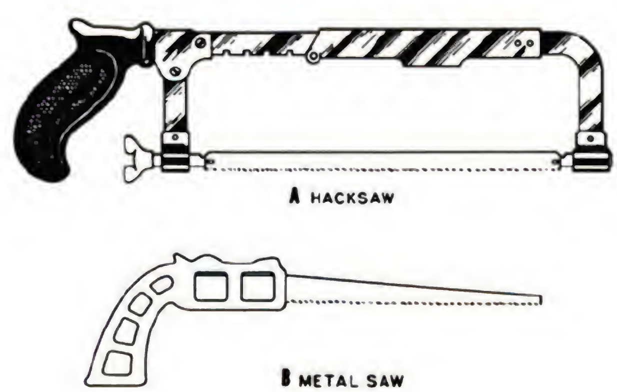
HACKSAWS AND METAL SAWS

A common type of hacksaw is shown in figure 4-6A. It is used for cutting metal, plastic, fibers, and other materials. It is a very useful tool when correctly used; however, it is often misused.

The frames are generally adjustable to take blades 8, 10, or 12 inches long.

The blades are of two general types—the flexible-back blade and the all-hard blade. Flexible-back blades are better suited for use on channel iron, tubing, sheet metal, copper, aluminum, babbit, etc., because it does not break as easily as the all-hard blade. The all-hard blade is used on brass, tool steel, cast iron, etc. because it does not have a tendency to buckle or run out of line when pressure is applied to it.

Details on the use of the hacksaws are given in Chapter 3 of the Electronic Installation Practices Manual, NavShips 900,171 and in Basic Hand Tools, NavPers 10085-A. However, the following suggestions will be helpful: (1) Adjust the wing nut until the blade is tight enough not to twist (it may be necessary to retighten the blade as it heats and expands during work); (2) hold the work fairly close to the vise to avoid spring and chatter; (3) hold



1.19

Figure 4-6.—Common types of hacksaw and metal saws.

the work securely to avoid loosening; (4) the forward stroke is the cutting stroke (blades should always be inserted with teeth pointing forward), and pressure should be relieved on the return stroke; (5) do not try to cut too fast; (6) do not use excessive pressure, and reduce the pressure when cutting thin material; (7) saw carefully when the blade is almost through the cut; (8) if a saw blade breaks when the cut is only partly completed, start the new blade in another place on the bar to avoid binding; and (9) coarse blades with fewer teeth per inch cut faster and are less liable to choke up with chips, but finer blades with more teeth per inch are necessary when thin sections are being cut.

The metal saw (fig. 4-6B) is used where it is inconvenient to use a hacksaw.

FILES

A flat file with the parts labeled is illustrated in figure 4-7A. Cross-sectional areas of the various types of files are illustrated in part B, and various cuts are illustrated in part C.

A detailed description of the various types of files are given in NavShips 900,171 and NavPers 10085-A, and therefore only a brief description of filing methods and file care is included here.

Proper filing methods come only with extensive practice. Of course, the first step is to choose the right file for the job. For example, a large, coarse, double-cut file should be used for heavy, rough cutting. When finishing the work, use a second-cut (40 teeth per inch) or a smooth single-cut (50 teeth per inch) file.

In working with cast iron, start with a bastard-cut and finish with a second-cut file; for soft steel, start with a second-cut and finish with a smooth-cut; for hard steel, start with a smooth-cut and finish with a dead-smooth one (100 or more teeth per inch); and for brass or bronze file with a bastard-cut (30 teeth per inch) and finish with a second- or smooth-cut file.

Be sure to raise the file slightly on the return stroke in order to clear the work and avoid dulling the file by wearing away the back of the teeth, thus destroying the cutting edges. This procedure does not hold true in the filing of soft metals, such as lead and aluminum. Drawing the file back along these metals on the return stroke aids in clearing the teeth.

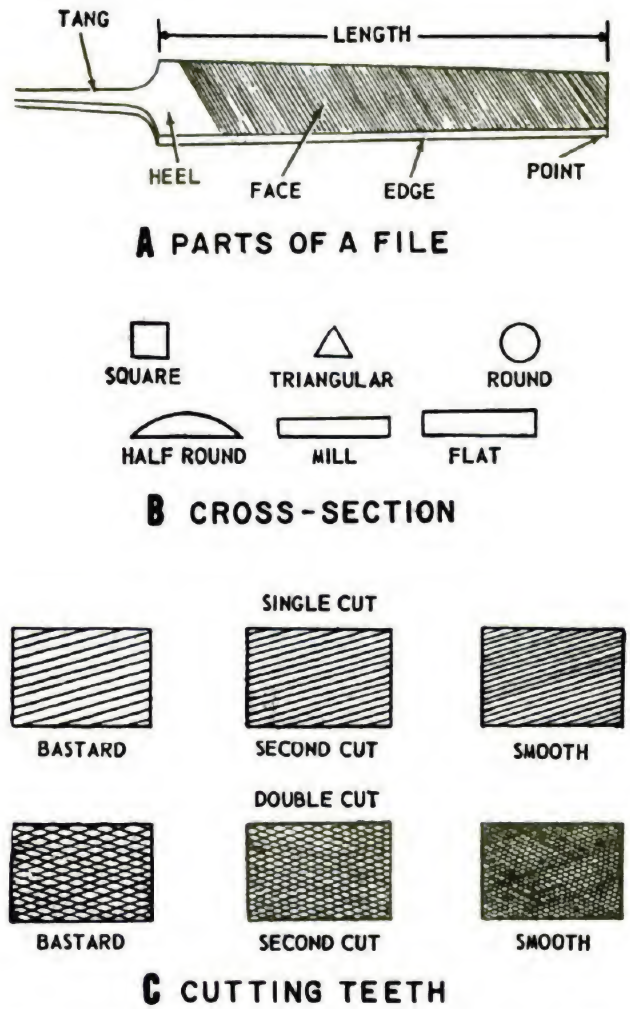


Figure 4-7.—Parts of a file, cross-sectional areas, and cuts.

Sometimes the material being filed tends to become clogged between the teeth of the file, causing scratches on the work. This is called PINNING. When pinning occurs, the file should be cleaned with a file card.

The following precautions should be kept in mind: (1) Select the proper type of file, (2) do not rub the hand over work being filed, (3) always use a file handle, (4) apply downward pressure only on the forward stroke, (5) do not hammer on or pry with files because they are brittle and will break easily, (6) do

not stow files in a box unprotected—especially do not pile them all together, and (7) remember that rust is the enemy of files the same as it is the enemy of other hand tools.

PLIERS

Some typical pliers used in electronics repair work are shown in figure 4-8. The Round-Jaw pliers (fig. 4-8A) are used for bending and shaping wire. They are especially useful for shaping wires for attachment to screw terminals (when lugs are not used).

Long-Nose or Needle-Nose pliers (fig. 4-8B and C) are used for removing and for replacing component leads. Actually, they are a necessity in removing leads from tie points and terminal strips and also in replacing the leads. They are often used with the soldering iron. These pliers should NOT be used in the place of a wrench or for bending metal or stiff wires. The bending of metals or stiff wires are jobs for heavier pliers—for example, Combination-Jaw pliers (gas pliers) (fig. 4-8D) or Short-Nose pliers (fig. 4-8E).

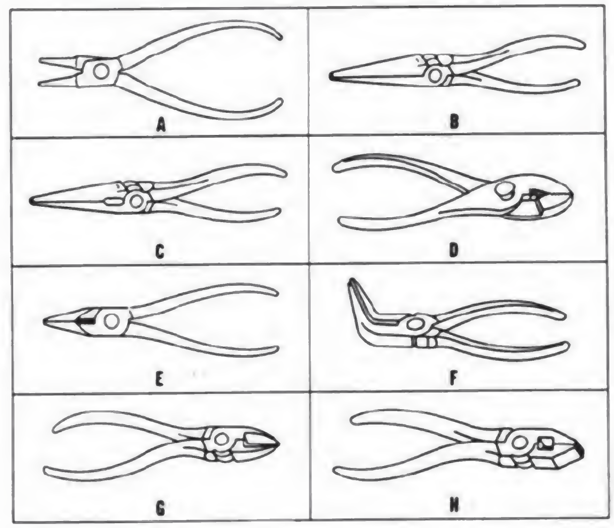
Curved Needle-Nose pliers (fig. 4-8F) are especially helpful in close spaces where the straight needle-nose pliers cannot reach.

In general, with the possible exception of the needle-nose type, pliers are rugged and require little care other than a drop of oil now and then and the proper cleaning. They should NOT be used for a hammer or a wrench. Hammering can loosen the jaws, and using pliers for a wrench can twist the jaws or loosen them sufficiently (especially the needle-nose type) to make them essentially useless.

Even the common "gas pliers" are not designed to be used as a wrench. Good technicians do not use pliers for wrenches.

Another very useful tool is the Diagonal-Cutting pliers (fig. 4-8G). Those shown in the figure have a cutting edge at a 15° angle to the plane of the handles. They are used for cutting small wire close to a flat surface. As a matter of fact, the CT M will find them useful for doing most of his wire cutting. A small (4-1/4 inch length) side cutter suitable for many types of work has the stock No. G5110-240-6209. The side cutters having stock No. G5110-224-1532 have special notches for splitting insulation and an insulation-stripping hole 0.052 inch in diameter.

Side cutting pliers (fig. 4-8H) are generally used for wire cutting and splicing work. Because



1.21

Figure 4-8.—Typical pliers used in electronics work.

the jaws and cutting edges are tempered, extreme heat should be avoided.

CIRCLE CUTTER AND CHASSIS PUNCHES

A circle cutter and two types of chassis punches are illustrated in figure 4-9.

The circle cutter (fig. 4-9A) will cut holes 1 to 5-1/4 inches in diameter in chassis material.

The operation is relatively simple. First, the size of the hole to be cut is determined; the cross arm is then adjusted so that the distance (X) between the center of the drill and point of the cutter is one-half the diameter of the hole to be cut.

The work should be placed on a wooden block and center punched at the exact center of the section to be cut out. This is the spot where the tip of the guide bit is placed.

The wood block should remain in place while the cutting is being done. Some cutters are made to fit a drill press; others are made to fit into a hand brace. In any case, pressure is exerted until the cutter has cut through the material.

In cutting a hole in sheet metal it is often easier to turn the sheet over after the metal has been cut half way through and finish the cut.

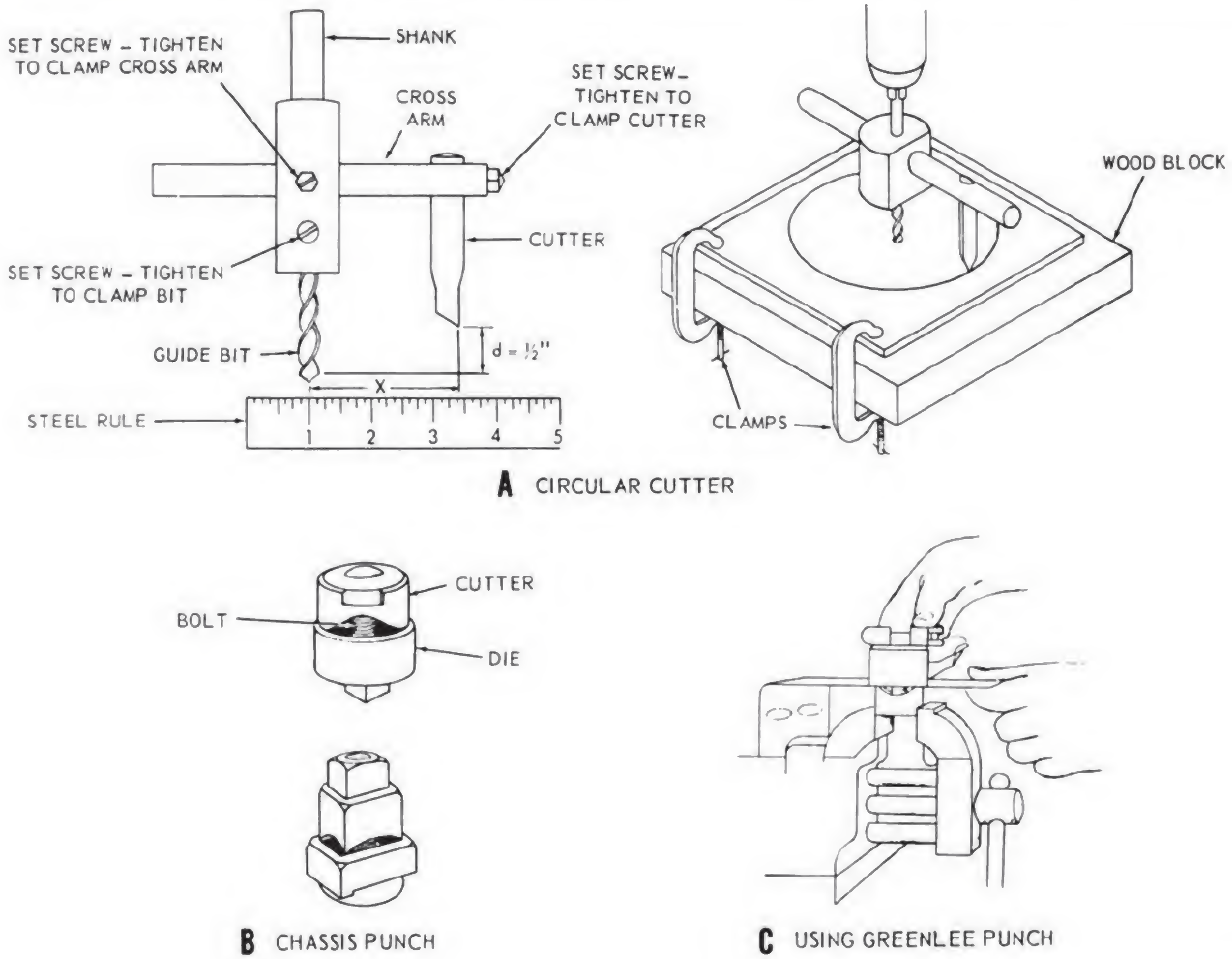


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Figure 4-9. —Circle cutter and chassis punch.

Two types of chassis punches are shown in figure 4-9B. One cuts a square hole and the other cuts a round hole. This is the most convenient way to cut holes larger then 1/2 inch in a chassis, provided the right size is available.

The round type is available in Navy stock in sizes from 1/2 to 1-1/2 inches; the square type is available in 5/8-inch square and a 3/4-inch square sizes.

A chassis punch generally consists of three parts: cutter, die, and bolt, as illustrated in the figure.

The cutter has two cutting edges symmetrically located for the proper balance and is threaded so that it can be drawn up against the chassis when the bolt is turned. A pilot hole of the correct size must be drilled in the chassis to receive the bolt.

A neat appearing hole can be cut in the chassis by the use of this type of punch. The method of using the punch is illustrated in figure 4-9C.

CRIMPING TOOL AND WIRE STRIPPERS

Solderless wire terminals serve a very important function in Navy electrical equipment. When these terminals are crimped with the proper tool, they have a pull-out resistance equal to the breaking strength of the wire. When properly installed, these terminals are

thoroughly dependable, both electrically and mechanically.

The Bureau of Ships has developed a universal crimping tool, shown to figure 4-10A, for use in installing solderless wire terminals. The tool makes a longitudinal crimp and is capable of attaching all approved type WT and WTG wire terminals (fig. 4-10B) to wire sizes from 1000 to 9000 circular mils. It is also designed to attach telephone wire terminals to wire having sizes from 250 to 1000 circular mils. Provision is also made for compressing the insulation-gripping shroud of WTG terminals.

Technicians who attach solderless wire terminals should use this tool. They should also have a good wire stripper that will remove the insulation from the wire without cutting any of the strands.

One type of wire stripper is illustrated in figure 4-11. Various blades are used to accommodate the various sizes of wire.

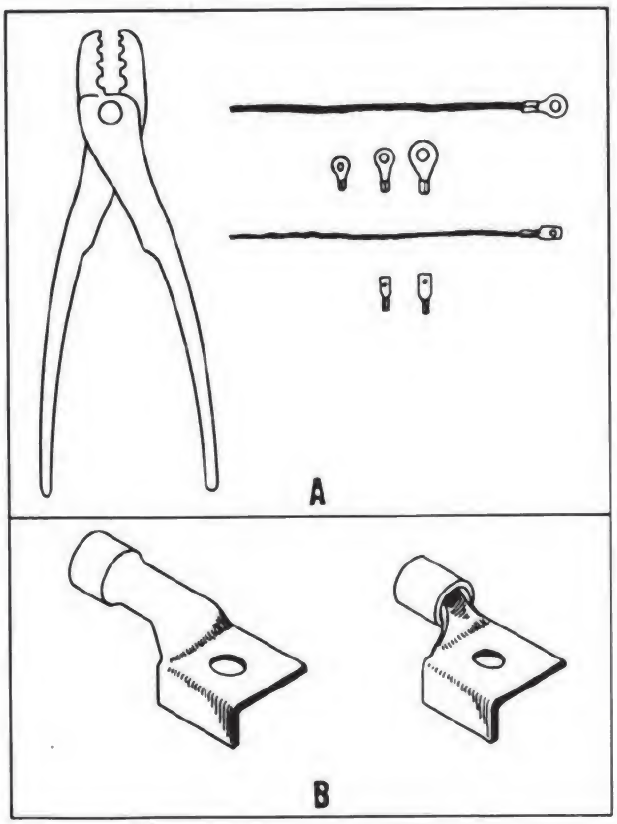

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Figure 4-10.—Universal crimping tool.

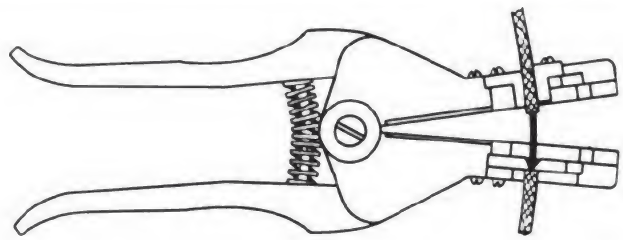

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Figure 4-11.—Wire stripper.

HAND AND PORTABLE ELECTRIC DRILLS

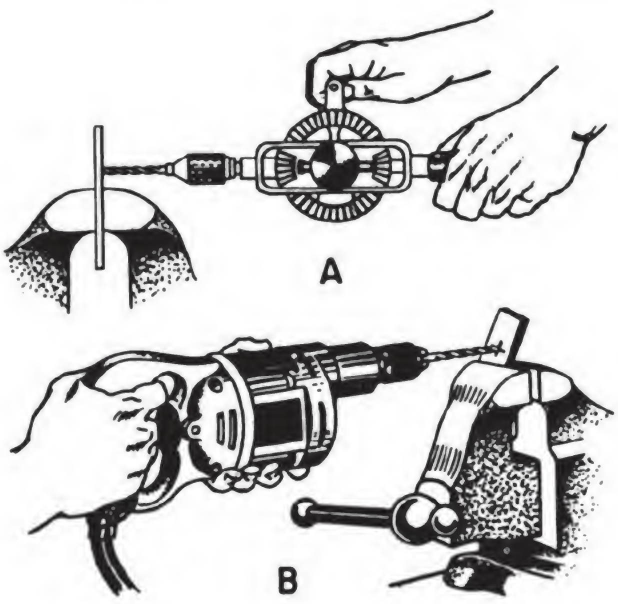
A hand drill and a portable electric drill are shown in figure 4-12. The hand drill (fig. 4-12A) generally accommodates twist drills (drill bits) up to 1/4 inch in diameter. To insert a twist drill, the chuck (the part that clamps the drill) jaws are opened sufficiently to insert the drill; after the drill is inserted, the chuck is tightened until the drill is held firmly. For heavy work, the larger hand-operated breast drill may be used.

A center punch should be used to provide a starting hole for the drill, thus preventing the drill from wandering and enabling the drill to start cutting without excessive pressure.

A Portable Electric drill (fig. 4-12B) is used whenever possible in drilling holes (except of course, when it is desirable to use a drill press) because it is easier and faster to use than the hand drill. This drill consists of a small geared-down portable electric motor with a drill chuck attached.

Drill chucks may be of the three-jawed gear type using a pinion key for tightening the chuck, or they may be of the two-jawed type with a socket head setscrew using an Allen, or hex, wrench for tightening. Do not leave the key in the chuck at anytime.

There are certain precautions that should be exercised when you use an electric drill: (1) Be sure that the drill case makes a positive connection to ground, (2) do not overload the drill by using a larger size drill than the largest size recommended, (3) always use a center punch, (4) hold the drill perpendicular to the work, (5) use an occasional drop of oil to keep the twist drill cool (if drilling in thick metal), (6) exert even pressure while the cutting is being done, (7) do not let the drill continue running in the hole, after drilling



1.25
Figure 4-12.—Hand and portable electric drills.

is complete (this will widen the hole), (8) do not hold the material you are drilling in your hand (clamp it down), (9) do not swing the drill by the power cord, and (10) do not lay a drill down or pull the plug while the drill is still running (use the switch on the drill first).

A Twist drill is a cutting tool designed to cut holes in most materials. It is usually made of either carbon steel or high-speed steel. If carbon steel is heated excessively it loses its hardness. High-speed steel can become red hot without losing its temper. When hard grades of steel (Monel and stainless) or certain plastics are to be drilled, the high-speed drill should be used.

The following suggestions will be helpful: (1) Sometimes it may be desirable to drill a pilot hole to keep larger drills from running off center: (2) when drilling thin pieces, secure them to a board before drilling; and (3) a squeak may indicate an improperly ground drill or the need for oil.

SOLDERING AND SOLDERING EQUIPMENT

ELECTRIC SOLDERING IRONS AND SOLDERING GUNS

Two of the most important hand tools used by the CT M are the electric soldering iron and soldering gun. This is true because soldering is the common method of making electric connections within electronic equipment; and it is a necessary part of nearly all repair procedures when a component, such as a resistor, capacitor, or inductor, is replaced.

Several general types of electric soldering irons are listed in the Navy Stock List of General Stores. Two of these soldering irons are shown in figure 4-13.

Figure 4-13A shows an a-c d-c soldering iron without thermostatic control. This is a standard type complete with copper tip and 6-foot cord. It operates on 110 volts a-c or d-c. The iron is available with pyramidal or chisel-shaped tip and at various wattage ratings.

For radio duty, the iron is rated at 85 watts and has a pyramidal tip.

Figure 4-13B shows an electric soldering-iron set equipped with built-in thermostat set to maintain heating element temperature between 700° and 775°F. The set includes handle, a full set of tips, and a resting stand. The tips are shown in part C.

The soldering gun (fig. 4-14) is extremely handy for light work. A soldering gun is a light-duty, fast-heating unit with built-in

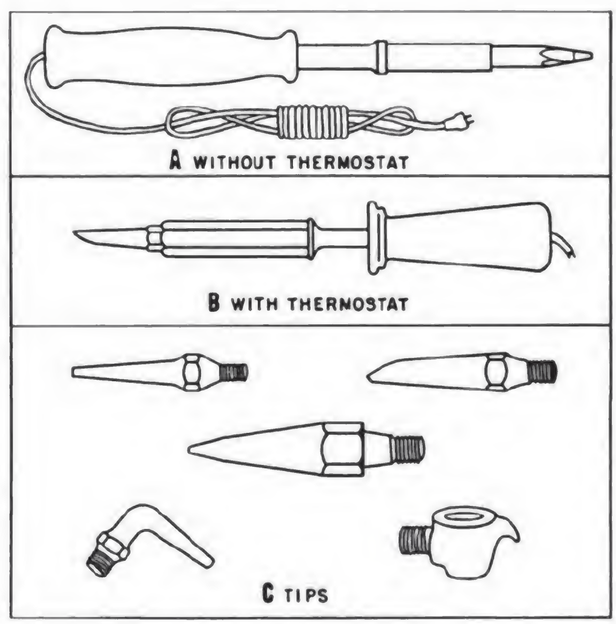


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Figure 4-13.—Electric soldering irons.

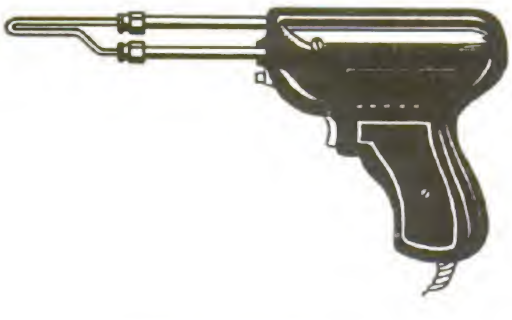

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Figure 4-14.—Soldering gun.

automatic spotlight. The tips are replaceable. The two-position switch (connected to the trigger) affords dual heat; the first position is 100 watts and the second position is 135 watts. The gun contains a transformer; its use is restricted to 115-volt 60-cycle operation only. It is NOT to be used on d-c.

The tip of the soldering gun is in the form of a narrow loop and makes a closed circuit with the secondary of the transformer. The flow of current through the tip heats it to soldering temperature in a matter of seconds. The gun is turned on and off for each soldering operation.

The cross-sectional area of the secondary winding is considerably larger than that of the soldering tip, and this tends to decrease the heating in the transformer and to concentrate it in the point where it is needed.

Continuous use of the soldering gun will overload the transformer and create the danger of a burn-out. Therefore, the trigger must not be held in the heating position continuously for long periods of time. Release it as soon as the soldering operation is over.

Gun tips should be maintained in the same manner as the tips of soldering irons.

In servicing transistorized circuits, two precautions must be observed. Use of low heat and use of a soldering iron or gun which does not inadvertently apply a harmful voltage surge to the transistor due to internal leakage.

A high heat level alone may be damaging to transistors. Consequently transistor manufacturers in general recommend the use of light duty soldering guns. If a light soldering gun is not available, light-duty 20- to 25-watt standard soldering irons may be used. Heavy duty irons should never be used directly on transistor circuits.

With regard to leakage within soldering irons or guns, faulty insulation or other causes may permit the a-c voltage to be applied to the transistor terminals during soldering operations. A careful check should be made of any soldering iron or gun intended for such use. This is done by checking with a voltmeter between the soldering iron or gun tip and the power ground with the tip at working heat. Two such tests should be made, reversing the a-c power plug the second time. In the event that leakage does occur, the iron may still be used either through an insolation transformer or by unplugging the iron temporarily while actually soldering.

SOLDERING

To a very large extent the efficiency and reliability of the electronic equipment used depends on the quality of the soldering done during assembly and during repair operations. Because shock and vibration can loosen poorly made joints (and perhaps cause an equipment to fail at a time when it is needed most), it is essential that soldered joints be properly made.

Be sure that the parts to be soldered are absolutely clean and free of oxide, grease, and insulation. The parts may be cleaned by scraping, filing, or sanding; but do not remove more of the material than is necessary. Avoid nicking or cutting the conductors because this will reduce the mechanical strength. The parts to be soldered must be mechanically secure and satisfactorily conductive before any soldering is done because solder has very little mechanical strength and has relatively poor electrical conductivity. The primary purpose of this solder is to ensure long lasting low-resistance contacts by preventing oxidation or loosening of the mechanical contact. As soon as possible after the joint has been prepared the soldering operation should be performed.

Solder is made of tin and lead. The best solder for general electrical work contains 60 percent tin and 40 percent lead and has a melting point of approximately 370° F (188°C).

Solder will not form a perfect bond with any metal if a film of oxide is present. Flux (Rosin Core Only for electronic soldering), when heated, removes oxides and prevents oxide from forming during the soldering process. The general practice in soldering electronic circuits is to use rosin-core wire solder. This

solder is in the form of a wire tube filled with rosin flux to form the core. Because the rosin has a lower melting point than the solder, the rosin flows out first to clean the surface when heat is applied. No residue of rosin should be left in the soldered joint. Excess rosin may be removed by use of alcohol.

The general procedure in making a soldered joint is given as follows: (1) Prepare the joint, as indicated previously; (2) heat the iron sufficiently to melt the solder readily; (3) heat the joint and quickly apply the solder; (4) apply only enough solder to ensure a good joint; (5) do not splash or throw the solder around, it is needed only on the joint; and (6) do not wiggle or jar the joint while the solder is cooling. (Any motion between the two halves of the joint before it cools will produce a "cold" joint, which has a dull white appearance instead of a shiny silvery appearance. If relative motion between the two halves of a joint occurs, it should be re-heated.)

A good soldering job requires a well-kept iron. The following suggestions will be helpful in retinning an iron: (1) When the tip becomes "pitted" by the action of the rosin core in the solder, retin the iron; (2) use a fine metal-cutting file to remove the pits, retaining the original shape of the tip; (3) heat the iron, rub the tip on sandpaper, and apply solder; and (4) wipe off the solder with a cloth.

Always select the proper tip for the job being done, and occasionally loosen the tip (fig. 4-13C) to ensure freedom from rusting of the threads so that it will not be difficult to remove. Soldering irons can usually be kept clean by wiping with a rag before corrosion starts.

FUSE PULLERS

Fuse pullers (fig. 4-15) are made of either laminated bakelite or fiber and are used for pulling and replacing fuses.

Fuses should never be pulled or replaced with the bare hands. Metal objects, such as a screwdriver, should never be used inside a fuse cabinet when attempting to remove or replace fuses. To be doubly safe, open the switch before pulling a fuse. Only in EMERGENCY REPAIRS will fuses be replaced while the circuit is still energized.

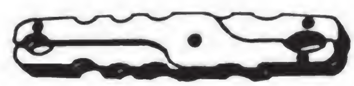

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Figure 4-15.—Fuse puller.

CHAPTER 5

TRANSISTOR CIRCUIT ANALYSIS

The use of transistors, crystal diodes, and other semiconductors in Naval electronic equipments is constantly increasing. Because of its versatility, the transistor is used in amplification, modulation and demodulation, and other electronic-circuitry applications. Its miniature dimensions make the transistor particularly suitable for use in unitized and modular constructed equipment (see Chapter 6). For the same reasons — miniaturization and compactness — trouble shooting in equipment containing transistors is made more difficult.

In Basic Electronics, Navy Training Course NavPers 10087-A, the theory of transistor operation and some transistor circuit applications are discussed. The discussion includes basic transistor amplifier arrangements, the characteristics of each arrangement, and some practical circuits which employ transistors. As you gain experience and acquire more responsibility, you will find it necessary to use a more detailed approach for circuit analysis. The purpose of this chapter is to present some techniques of transistor circuit analysis and some of the terms used in specifying transistor characteristics. A knowledge of these techniques and terms will provide the technician with the necessary background for making modifications and adjustments and performing corrective maintenance on transistor circuits.

As a review, study figures 5-1, 5-2, and 5-3, which illustrate the three basic transistor amplifier arrangements and the corresponding vacuum-tube amplifier arrangements. Notice the polarities of the supply and bias voltages used in each arrangement. These polarities are proper for ordinary amplifier operation. Table 5-1 shows the relative characteristics of three basic arrangements.

TRANSISTOR FACTORS

TRANSISTOR SPECIFICATIONS

Semiconductors, like vacuum tubes, are available in a large variety of types, each with its own unique characteristics. The characteristics of each of these devices are usually presented in "Specification Sheets", or they may be included in tube or transistor manuals. The specifications usually cover the following items:

1. The lead paragraph of a semiconductor specification sheet is a general description of the device, and contains three specific pieces of information:

   a. The kind of semiconductor: This covers the semiconductive material used, such as germanium or silicon; whether type PNP or NPN, etc., and the type of construction, whether alloy-junction, grown or diffused junction, etc.

   b. Some of the major applications are listed, such as audio amplification, oscillator, high-gain RF amplification, etc.

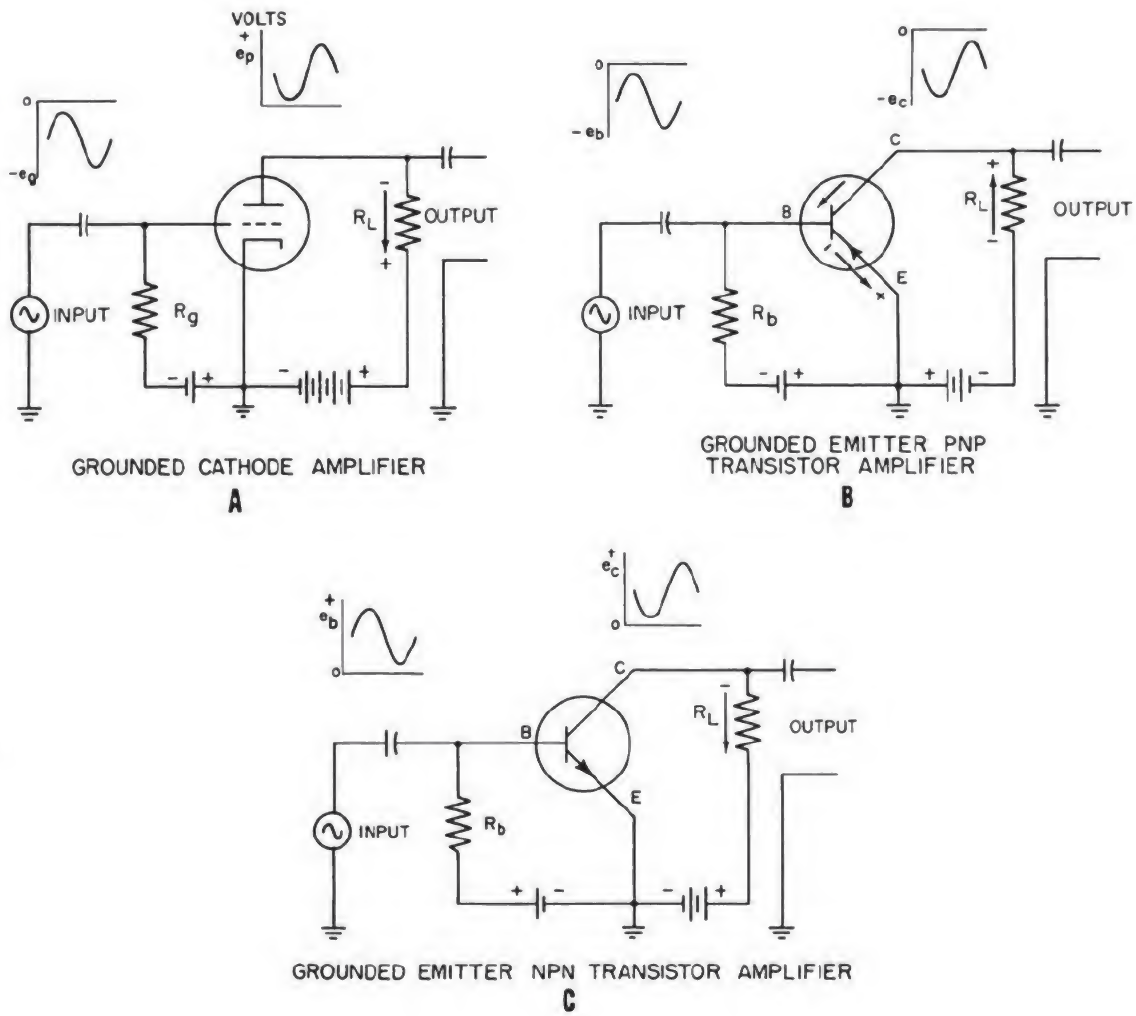
   c. General sales features, such as size and packaging.

2. The "Absolute Maximum Ratings" of voltages and collector current: These ratings should not be exceeded under any circumstance, as semiconductor failure may result.

3. Collector power dissipation: The power dissipation of a transistor is a function of its junction temperature and the ambient temperature. The higher the temperature of the air surrounding the transistor, the less power the device can dissipate. A factor telling how much the transistor must be de-rated for each degree of increase in the ambient temperature is usually given.

Table 5-1. —Characteristics of the Three Common Transistor Arrangements.

CIRCUIT CONFIGURATION		
Common Emitter (CE)	Common Base (CB)	Common Collector (CC)
Characteristics—	Characteristics—	Characteristics—
moderate input impedance	lowest input impedance	highest input impedance
moderate output impedance	highest output impedance	lowest output impedance
high current gain	low current gain	high current gain
high voltage gain	high voltage gain	unit voltage gain
highest power gain	moderate power gain	lowest power gain



1.281

Figure 5-1.—Corresponding electron-tube and transistor amplifiers.

4. Current transfer ratio: This is another name for alpha or beta.

5. Collector cutoff current: This is the leakage current from collector to base when no emitter current is being applied.

Additional information is provided for engineering-design purposes.

ABSOLUTE MAXIMUM RATINGS

For each transistor there are certain absolute maximum ratings which cannot be exceeded without damaging the transistor. These maximum ratings are included in the specifications for each type of transistor, as listed in transistor manuals, and are usually given the following abbreviations:

BV_{CE} = Breakdown voltage, collector-to-emitter

I_C = Collector current

$P_{C(25^\circ C)}$ = Collector dissipation at 25° centigrade (ambient temperatures)

Breakdown voltages are sometimes given for each of the junctions by specifying absolute maximum ratings of V_{CBO} (collector-to-base),

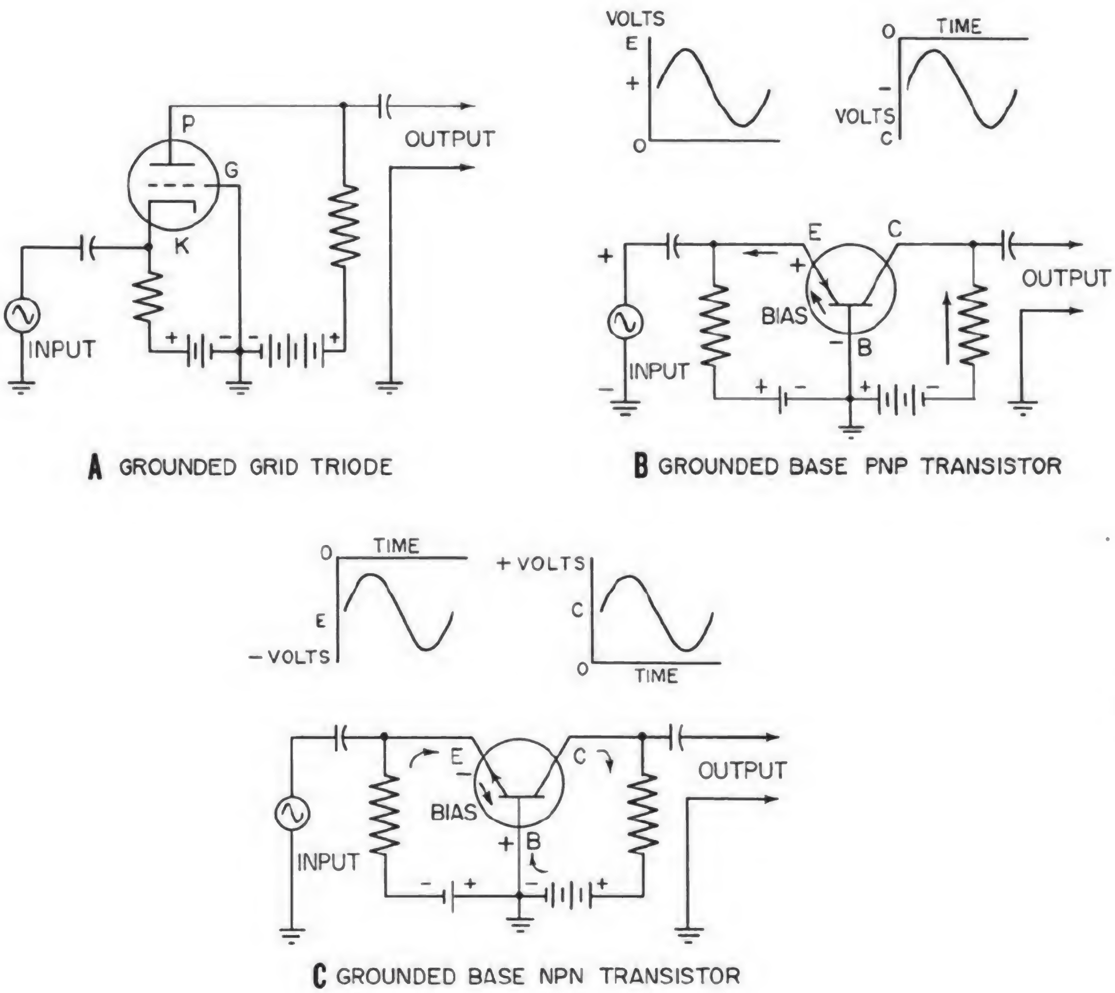


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Figure 5-2.—Grounded grid triode and corresponding grounded-base transistor amplifiers.

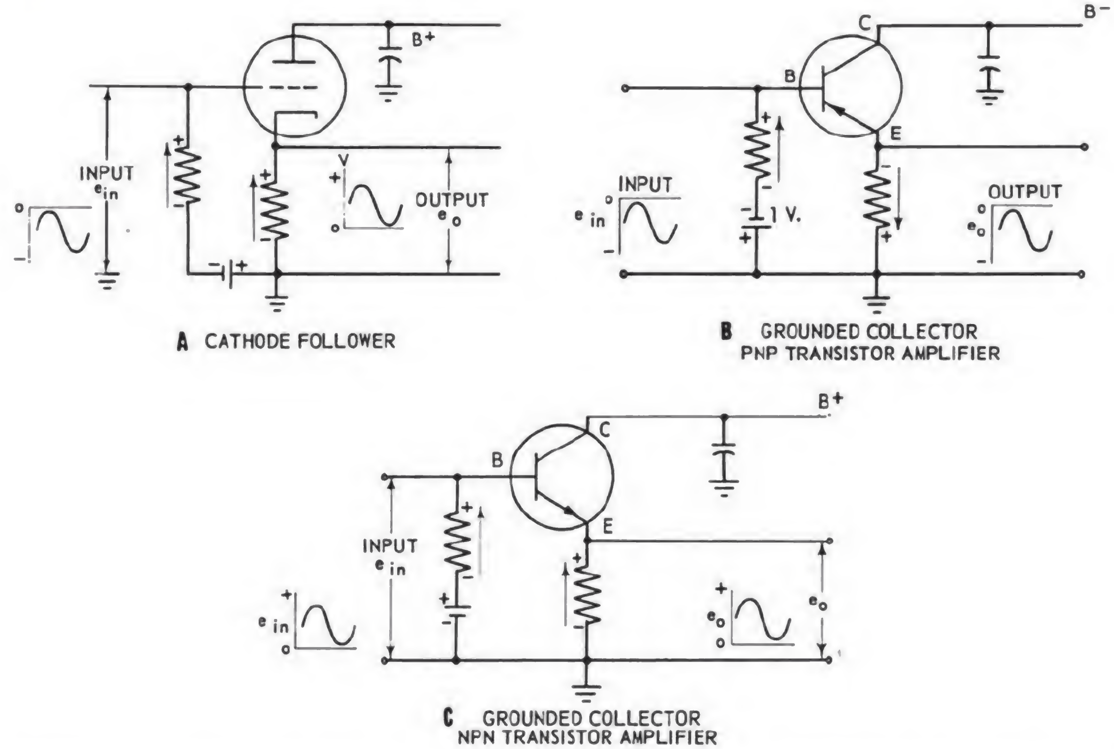

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Figure 5-3.—Electron tube cathode follower and corresponding grounded-collector transistor amplifiers.

V_{CEO} (collector-to-emitter), and V_{EBO} (emitter-to-base). Complete specification sheets for particular transistors will ordinarily include the maximum ratings. However, in abbreviated specification sheets, cross-reference tables, etc., only BV_{CE} or BV_{CB} are normally given because they are of interest in the largest number of applications.

Transistor specifications usually state that the given ratings and characteristics are established for an ambient temperature of 25° C. However, because the maximum collector dissipation is greatly reduced as the ambient temperature is raised, the collector dissipation rating is always accompanied by the corresponding value of ambient temperature. In addition, the specifications usually give a factor telling how much the maximum collector dissipation must be de-rated for each degree (Centigrade) rise in temperature. For example, if the specifications state that the absolute maximum P_C (25° C) is 60 mw and that the collector dissipation should be derated 2 mw for each °C rise above 25° C, if the ambient temperature is raised to 35° C, the maximum collector dissipation is reduced to only 40 mw. If the ambient temperature is raised to 55° C, it will be impossible to operate the transistor because the maximum collector dissipation will be reduced to zero.

Excessive temperatures will cause permanent damage to transistors, both in and out of operation. Therefore, specifications usually include a maximum junction operating temperature (T_J) rating and a maximum storage temperature (T_{STG}) rating. Transistor specifications of maximum collector-to-emitter voltage, collector current, and collector dissipation correspond to vacuum-tube specifications of maximum plate-to-cathode voltage, plate current, and plate dissipation.

DIODE AND TRANSISTOR DESIGNATION SYSTEM

A standardized system of numbers and letters is used for designating diodes and transistors:

1. The first number indicates the number of junctions. Thus, 1 designates a diode; 2

designates a transistor (which may be considered as made up of two diodes, the base-emitter and base-collector diodes); 3 designates a tetrode, a four-element transistor.

2. The letter N following the first number indicates a semiconductor.

3. The 2- or 3-digit number following the letter N has no particular significance, except that it indicates the order or registration. When this number is followed by a letter, it indicates a later, improvised version.

Thus, a semiconductor designated as type 2N345A signifies that it is a three-element transistor of semiconductor material and that it is an improved version of type 345.

TRANSISTOR LEAD IDENTIFICATION

The arrangement and coding of transistor leads is shown in figures 5-4. Figure 5-4A shows a transistor in an oval case. The collector lead is identified by a wide space between it and the base lead, which, in turn, is followed by the emitter lead. Figure 5-4B shows a round case with the three leads in line and equally spaced. The collector lead is marked on the case by means of a color dot, usually red. The other two leads are the base and emitter, in that order. In figure 5-4C, the collector lead is marked by a red line on the case. The base and emitter leads follow clockwise around the circle, in that order. In figure 5-4D the leads are located at three points of a quadrant. When viewed from the bottom in a clockwise direction, the first lead following the blank space is the emitter, followed by the base and collector. Figure 5-4E shows a conventional power transistor where the collector is connected to the mounting base, the mounting bolt forming the conductor for the collector. The base lead is identified by its green sleeving.

It should be noted that sometimes, even where all three leads are present, one of the elements may be connected to the mounting base to provide additional cooling.

Figure 5-4F shows a tetrode. The collector is identified by the wide space between it and the other leads, which are: base 2, base, and emitter, in that order.

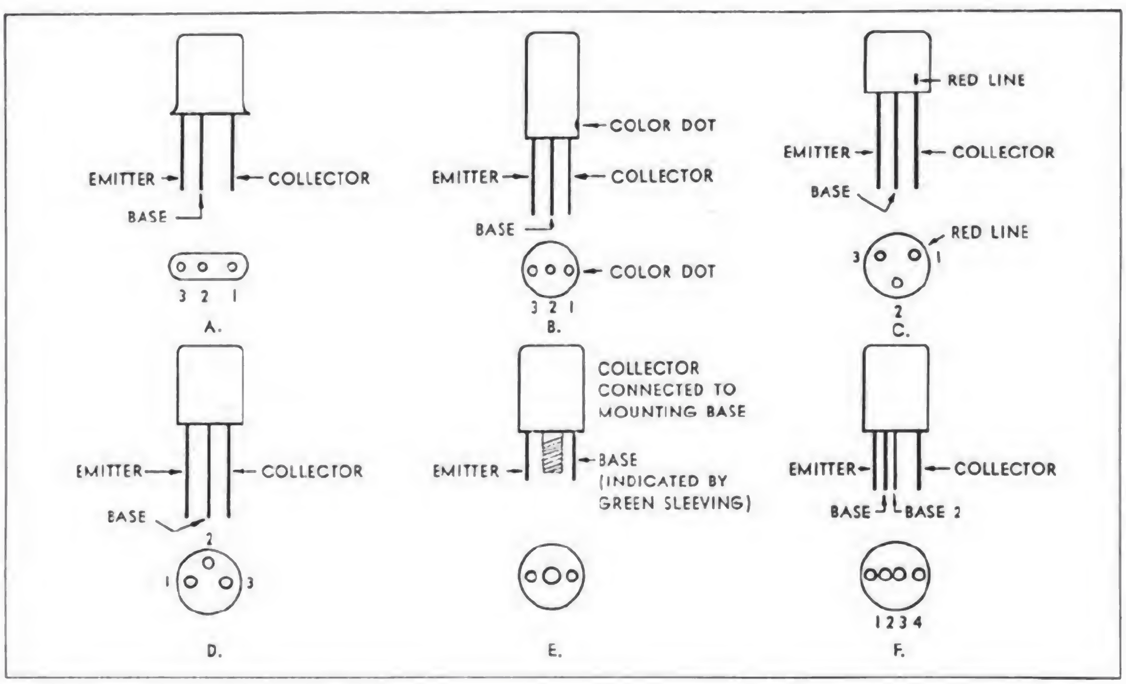

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Figure 5-4.—Transistor lead identification.

COLOR CODING OF SEMICONDUCTOR DIODES AND RECTIFIERS

A new standard system of color coding has recently been adopted by the Electronic Industries Association for the identification of semiconductor diodes and rectifiers in the 1N series. In the new system the 1N has been omitted from the color scheme, and the Joint Electronic Device Engineering Council (JEDEC) type number following the letter N is now indicated by color bands. In the two-digit series, the first band is black, the two-digit series is required, it is indicated by a fourth band. The color code is read from the cathode end of the semiconductor diode or rectifier. The first color band may be double width, or all color bands may have equal width. By referring to table 5-2, it can be seen that a 1N34A would be color coded black, orange, yellow, and brown. For those items with four digits and a suffix, there are five color bands. For example, a 1N2171A would be color coded red, brown, violet, brown, and brown.

Table 5-2.—Color Coding of Semiconductor Diodes and Rectifiers.

Number	Color	Suffix Letter
0	Black	-
1	Brown	A
2	Red	B
3	Orange	C
4	Yellow	D
5	Green	E
6	Blue	F
7	Violet	-
8	Gray	-
9	White	-

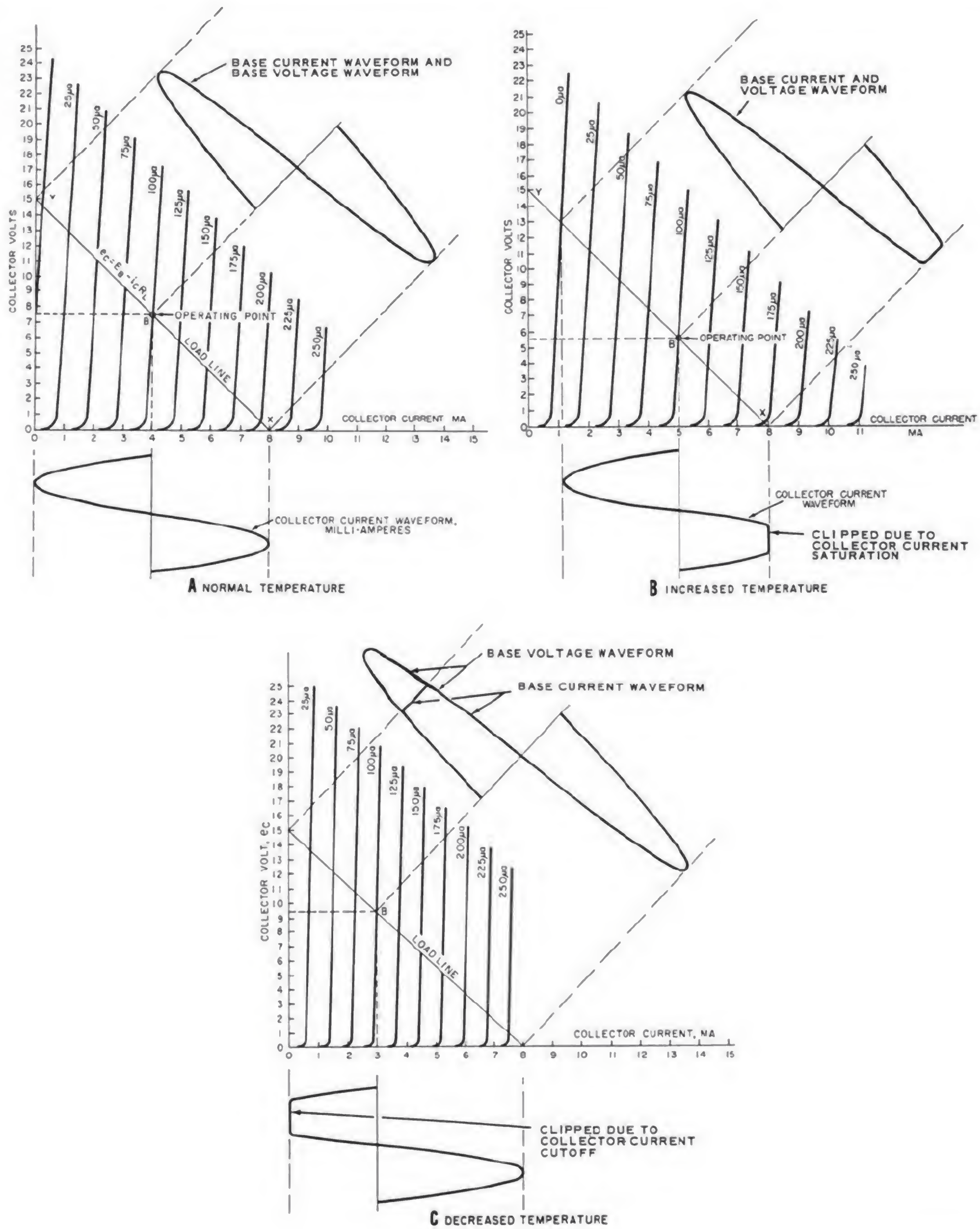
EFFECTS OF TEMPERATURE ON TRANSISTOR OPERATION

TRANSISTOR CHARACTERISTICS CHANGED BY TEMPERATURE VARIATION

Transistor characteristics change considerably with temperature variation. One of the most important characteristics which is temperature dependent is collector-base leakage current. When the collector-base circuit is reverse biased, some current will flow even when the emitter current is zero. This current is due primarily to minority carriers present in the base and collector regions. In transistor specifications, the leakage current is usually designated I_{co} or I_{cbo} and is known as collector cutoff current. It is so designated because of the method used to determine leakage current; it is the collector-base current which flows in the reverse-biased collector-base circuit when the emitter current is zero (emitter open). Because it is temperature dependent, I_{co} is specified for a particular temperature, usually 25° C. A typical rating would be I_{co} = 10 μ amps at 25° C. The collector-base voltage is usually specified. However, I_{co} is usually independent of both emitter current and collector voltage when collector voltage is greater than a few tenths of a volt. Therefore, I_{co} is often referred to as saturation current.

Under normal operating conditions, I_{co} is small compared to the other currents in the circuit; but as temperature increases, I_{co} increases, normally doubling in value at approximately each 10° C rise in temperature. If the temperature rise is sufficient, I_{co} becomes a significant portion of the collector current. Since I_{co} is in the collector circuit, it contributes to collector dissipation. As collector dissipation increases due to increased I_{co}, the collector junction temperature rises causing a further increase in I_{co}. Unless steps are taken to provide additional cooling in order to prevent a further rise in temperature, or compensating circuits added which will tend to decrease collector current as temperature increases, a regenerative cycle begins which will continue to increase collector current and dissipation until the transistor is damaged and burns out.

Figure 5-5 indicates the effects of temperature variations on the static characteristic curves of a transistor. Figure 5-5A represents the constant base current curves of collector voltage versus collector current for normal temperature operation. Figure 5-5B represents curves for the same transistor with above normal temperature operation. The effect of increased temperature moves the curves to the right along the X axis (mainly due to increased I_{co}) and may increase their spacing. Since the bias current has been fixed by the circuit configuration at 100 μ amps, the action due to increased temperature shifts the operating point B on the load line toward point X, making the collector voltage too low. For class A operation, the normal collector voltage at point B is 7.5 volts. The increase in temperature moves



20.164-.166

Figure 5-5.—Effect of temperature variations on NPN transistor characteristics.

point B to a position, indicated in 5-4B, that corresponds to a collector voltage of 5.5 volts.

Conversely, the effect of a decrease in temperature moves the curves to the left along the X axis and tends to reduce their spacing (figure 5-4C). The action shifts the operating point along the load line toward point Y, making the collector voltage too high. The operating point now corresponds to a collector voltage of 9.5 volts.

TEMPERATURE COMPENSATION

The apparent shift of operating point due to temperature variation will cause distortion of the output signal as indicated in figure 5-5. And, as pointed out earlier, the increased collector current which results from increased temperature may cause the transistor to burn out. These adverse effects may be partially remedied by connecting the bias resistor directly between the collector and base as illustrated in figure 5-6, a circuit in which R_B is in series with the emitter-base circuit. As in the previous example, it is desired to provide a condition wherein the no-signal collector voltage will be 7.5 volts and the no-signal base current will be 100 μ amps. For this condition, R_B is determined by

$$R_B = E_C / I_B = \frac{7.5}{100 \times 10^{-6}} = 75,000 \text{ ohms}$$

As in the fixed bias arrangement, the polarity of the voltage drop across the base-emitter junction is such as to make the emitter negative with respect to the base. The polarity corresponds to the forward direction for the base-emitter NPN junction transistor.

With the described type of self bias, a change in temperature will affect the magnitude of the bias current. For example, if an increase in temperature occurs, the tendency for the collector current to increase will be accompanied by a decrease in collector voltage across R_B, with a corresponding decrease in base bias current through R_B. The action will tend to shift the operating point along the load line upward to the left of point B (figure 5-4B) and thus to reduce the amount of distortion caused by the temperature increase.

Conversely, a decrease in temperature will be accompanied by a tendency for the collector current to decrease and the collector voltage across R_B to increase. The increase in voltage

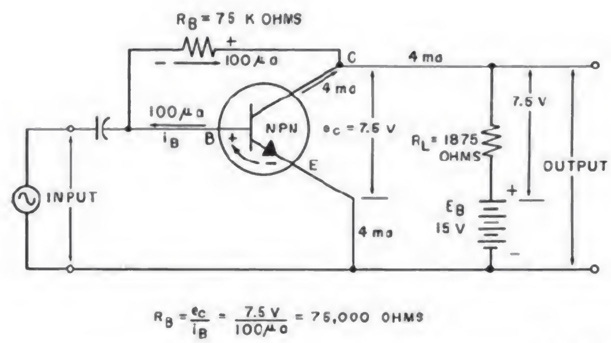


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Figure 5-6.—Transistor self bias.

across R_B will increase the base bias current through R_B and shift the operating point along the load line downward and to the right of point B (figure 5-4C), again reducing distortion.

Thus, self bias provides an action that tends to partially compensate for temperature changes. In addition, self bias provides negative feedback, which is similar to that provided by an unbypassed cathode resistor in an electron-tube amplifier, and which reduces the effective gain of the transistor amplifier.

In the transistor amplifier illustrated in figure 5-7, resistor R_B provides fixed bias for class A operation, and resistor R_E provides circuit stabilization to prevent temperature changes from altering the transistor characteristics. Resistor R_E also prevents damage to the transistor by limiting the magnitude of the collector current to the maximum safe value for the highest temperature to be encountered during operation.

If the temperature increases, the increase in collector current through R_E will lower the emitter voltage, tending to prevent further increase in collector current and therefore preventing the shift of the characteristic curves to the right along the X axis (figure 5-4B). Conversely, a decrease in temperature will lower the collector current through R_E and the voltage drop across R_E, increasing the collector voltage and tending to prevent further reduction in collector current so that there will be less shift of the characteristic curves to the left along the X axis (figure 5-4C).

The value of R_E is equal to the value of R_L for maximum protection. The efficiency is reduced from 50 percent in figure 5-6 for maximum power output to 25 percent in figure 5-7. It

is believed that most transistor audio power amplifier circuits will be satisfactorily stabilized if the value of R_E is not more than 10 percent of the load resistance for maximum power output. In figure 5-6 according to the desired relation, R_E = 0.1 x 1875, or 187.5 ohms, and the power dissipated in R_E will be 10 percent of the power output of the stage.

If the resistor R_1 is added to the circuit of figure 5-7, another return path for collector current will be provided around R_E. If R_1 is relatively low resistance compared to R_E, most of the collector current will flow through R_1 reducing the signal component of collector current through R_E with less degeneration and increased stage gain. On the other hand, more power will be wasted at the input. There will also be less change in input impedance and less change in input circuit loading.

In order to prevent degeneration from occurring across the stabilizing resistor R_E (figure 5-7), a bypass capacitor C_E is connected in parallel with R_E in the emitter circuit. The resulting action is similar to that occurring in the cathode bypass capacitor in parallel with the cathode resistor of a cathode biased electron-tube amplifier. In order to bypass the a-c component around the resistor without developing a voltage at the signal frequency across the resistor, the reactance of the bypass capacitor should be low with respect to the resistance of the resistor. For most audio transistor amplifiers the bypass capacitor need not be larger than about 50μf.

The coupling capacitor C_c must be large enough to pass the lowest frequency signal without appreciable phase shift or reduction in magnitude of the signal. The lowest frequency to be passed is the frequency at which there is a reduction in amplitude of 3 db. At this frequency the reactance of the coupling capacitor is approximately equal to the input resistance of the transistor amplifier stage. In the example of figure 5-7, the input resistance is approximately 1000 ohms and consists essentially of the resistance between the transistor base and emitter in the forward, or low-resistance, direction. If the lowest frequency to be passed is 100 cycles per second, the X_C of C_c will equal the input resistance or 1000 ohms. The capacitance of the coupling capacitor is found as follows:

$$C_c = \frac{1}{2\pi fX_c}$$

$$= \frac{1}{6.28 \times 100 \times 1000}$$

$$= 1.59 \times 10^{-6}$$

$$= 1.59\mu f$$

A 2 μf capacitor would expand the low frequency limit to about 80 cycles per second.

MAINTENANCE OF TRANSISTORIZED CIRCUITS

There is a great similarity between the functions of a transistor and the functions of a vacuum tube; thus, any knowledge picked up by

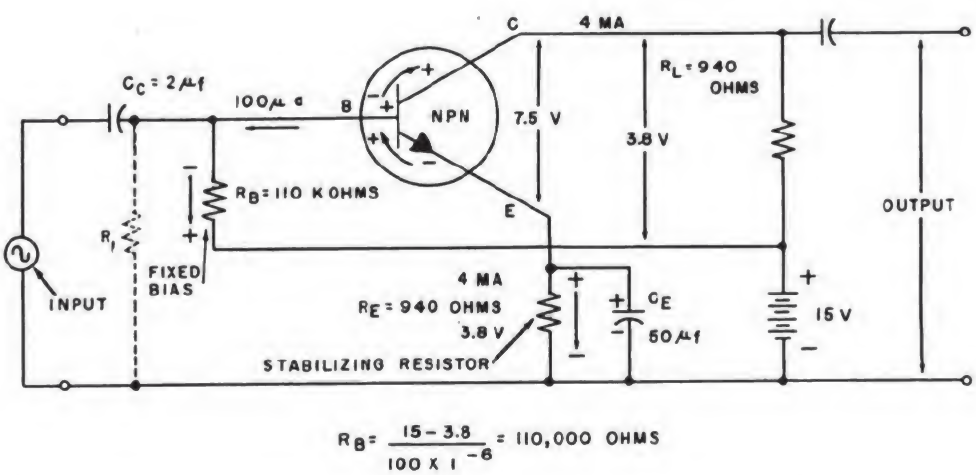

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Figure 5-7.—Transistor amplifier with fixed bias and circuit stabilization.

the electronic technician in his work on vacuum-tube equipment will be useful in the servicing of transistorized circuits. The same procedure for localizing a defect may be used for transistorized equipment as for vacuum-tube circuits. However, there are great differences between a transistor and a vacuum tube from the standpoint of servicing. For instance, it is not feasible to look into the equipment and tell whether or not a transistor is energized, as in the case of most vacuum tubes. Also, since a transistor develops very little heat, nothing can be learned by feeling a transistor. High-frequency transistors hardly get warm. Usually, if a transistor is hot enough to be noticeable, it has been damaged beyond use (except special or high-power transistors).

In the servicing of a vacuum tube, which is usually of the plug-in type, a quick test is sometimes made by the "substitution" method, that is, by replacing the tube suspected of being faulty with a new one. Transistors are frequently soldered and substitution becomes impracticable. Furthermore, indiscriminate substitution of semiconductors should be avoided; it is preferable to test transistors "in-circuit."

The technician will find more transistors than tubes in two similar equipments, which means more stages to check out. This is true because of the lower gain and power capacity of the transistor.

TROUBLE SHOOTING IN TRANSISTOR CIRCUITS

The first step in checking for trouble in transistor circuits is a thorough visual inspection of the equipment. Loose connections, broken leads, corroded battery terminals, etc., should be corrected. A careful visual inspection may save many hours of trouble shooting.

Since the transistor is probably one of the most reliable components, it should be the last to be suspected. This is contrary to the long established practice used in vacuum-tube equipments, where the tubes normally are checked first. Because of their reliability, transistors are generally soldered in the circuit—particularly in printed circuits. Removing and testing each transistor will not only unnecessarily subject the transistor to heating, but may also result in damage to some other component, particularly in the case of a printed circuit board.

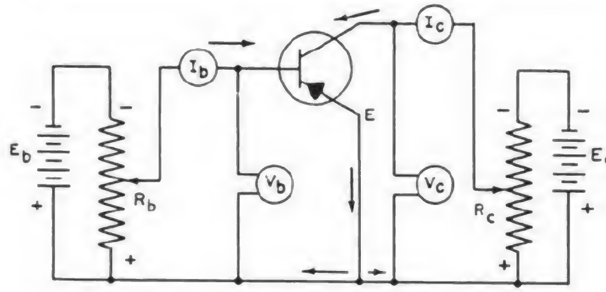
If it is possible to leave the equipment in operation, a scope could be used to trace the signal from stage to stage, from input to output. If the equipment is not in operation, signal substitution can be used, inserting signals of the proper waveshape and amplitude at appropriate places in the circuit. When using signal substitution, it is especially important that the signal amplitudes used are not larger than those designed for, since transistors are easily damaged if subjected to voltages above rating. In all cases, no matter what type of test equipment is being used, MAKE CERTAIN THAT THE TEST EQUIPMENT CHASSIS GROUND IS SECURELY FASTENED TO THE CHASSIS GROUND OF THE EQUIPMENT UNDER TEST. Sometimes, due to insulation leakage, etc., fairly high potentials are present between pieces of equipment if they do not have a common ground. If these voltages are placed across a transistor, damage is likely to result.

CIRCUIT ANALYSIS BY THE USE OF LOAD LINE

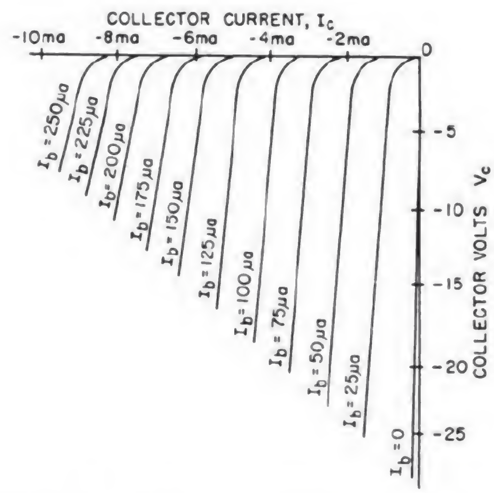
The Load Line

The output voltage and current components of a transistor audio amplifier which result from a given input signal current can be determined by the use of the static characteristic curves of the transistor in a manner similar to the use of static characteristic curves of a vacuum tube for vacuum-tube circuit analysis. Because the grounded-emitter arrangement is most often used for ordinary linear audio amplification (i.e. output signal identical to input signal except for amplitude), the following discussion is based on a grounded-emitter, class-A amplifier in which an NPN transistor is the amplifying component. The static characteristic curves which are used in the discussion were developed by means of a test circuit similar to that shown for a PNP transistor in figure 5-8 (All supply and bias batteries were reversed for the NPN test circuit.)

The transistor audio amplifier circuit and the characteristic curves for the example are shown in figure 5-9. The loan line XY is a graph of the equation $e_C = E_B - i_C R_L$, where e_C is the instantaneous collector-to-emitter potential, E_B is the collector supply voltage, and $i_C R_L$ is the voltage drop across the load resistor, R_L.



A PNP TRANSISTOR GROUNDED EMITTER CIRCUIT



B TRANSISTOR CHARACTERISTICS 1.282

Figure 5-8.–Grounded-emitter PNP junction transistor static characteristics.

Point Y is established as $e_C = E_B$, the condition which exists when the collector current is zero; the full value of the collector supply voltage appears between the collector and the emitter because there is no voltage drop across R_L. In this example, the load line intersects the collector voltage axis at V_C = 15 volts since E_B = 15 volts.

Point X is established as $i_C = E_B \,/\, R_L$, the condition which exists when the base current is increased to the point where the effective internal resistance of the collector-emitter circuit is reduced to zero. For this condition, the collector current would become a maximum value and the collector supply voltage would appear across the load resistance. In this example, the load line intersects the collector current axis at $i_C = E_B \,/\, R_L = 15/1875 =$ 0.008 ampere, or 8 ma.

Load Resistance

In the foregoing paragraph, the value of load resistance was used to determine the point at which the load line intersects the current axis. If, however, one first determines the load line by choosing the points X and Y, the value of the load resistance can be determined as the voltage value at point Y divided by the current value at point X. In this example, the value is 15 volts divided by 0.008 ampere or 1875 ohms.

It is common practice to have available a fixed supply voltage (which establishes point Y) and to choose the operating point B. The two points, Y and B, then establish the load resistance in the following manner: $\dfrac{R_L = E_B - E_C}{I_C}$

where E_C is the collector-to-emitter voltage at the operating point B, I_C is the collector current at this point, and the other terms retain their previous meanings. In this example,

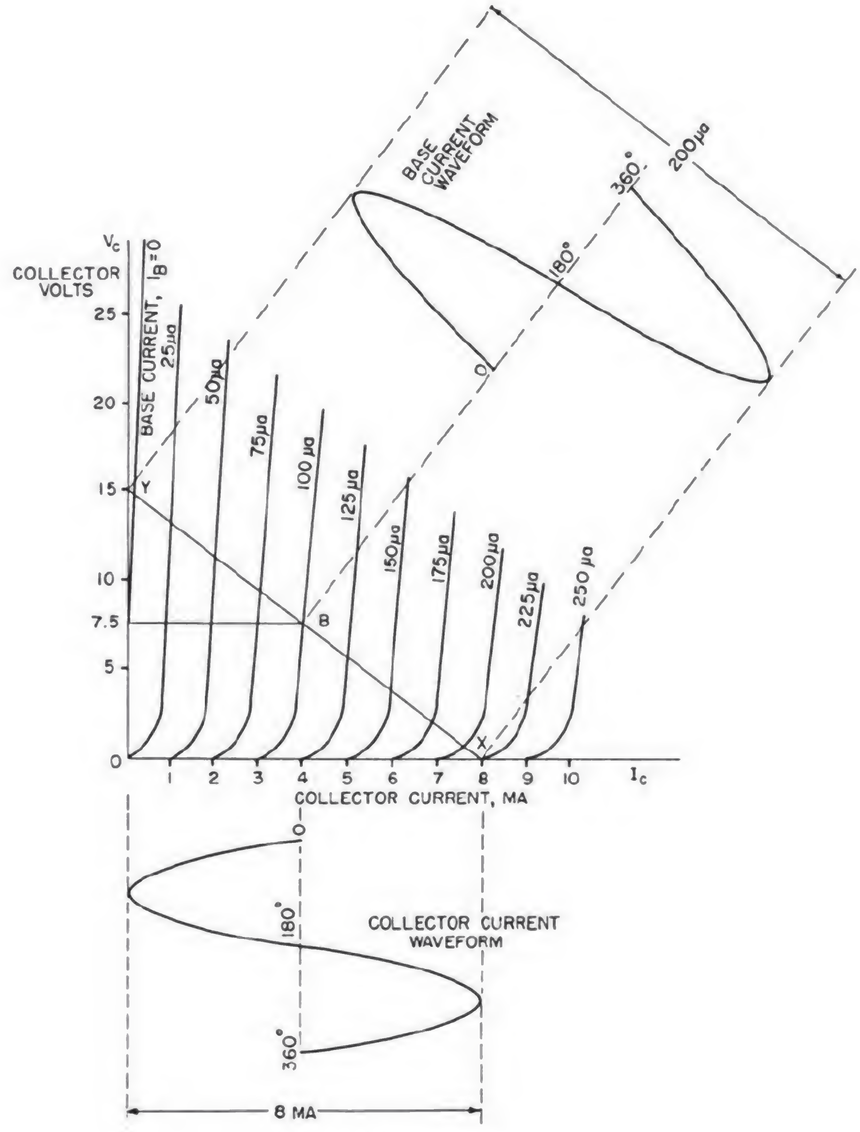
$$R_L = \frac{15 - 7.5}{0.004} - 1875 \text{ ohms}$$

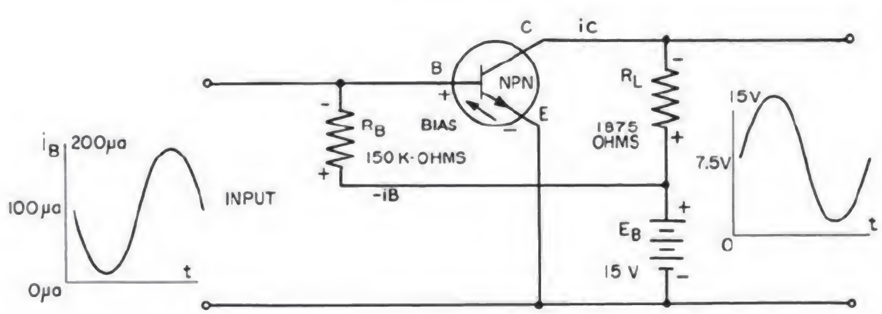
The characteristic curves for many transistors will not be as evenly spaced for all values of base current as are the curves in figure 5-9. In general, the curves tend to become closer together as the base currents are increased. If the load line intersects curves which vary in spacing, there will not be a linear relationship between base current (input signal) and collector current (output signal) over the entire load line. If the amplifier operates over the entire load line when no linear relationship exists, the output signal will be distorted.

When designing or modifying a transistor amplifier, the final choice for a value of load resistance (and thus the resulting load line) depends on many factors. It must be ascertained that none of the absolute maximum ratings for the transistor are ever exceeded; the final choice may be influenced by whether or not any distortion is permissible in the output; and, the choice will depend on the available supply voltages and circuit components.

Bias

The operating point B has the same significance as the operating point for vacuum-tube circuits; it represents the no-signal condition.





CIRCUIT

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Figure 5-9.—Transistor class A audio amplifier.

In the example, the operating point has been chosen at the point where base current (bias) is 100μ amperes. The bias current may be obtained by connecting a resistor of the proper magnitude between the base terminal and the positive terminal of E_B. In the example the magnitude of the resistor is determined as:

$$R_B = E_B / I_B = 15/ (100 \times 10^{-6}) = 15,000 \text{ ohms}$$

where I_B is the base current at point B. Actually, the value of R_B determined in this manner also includes the internal base-emitter resistance; but this internal resistance (which is a few hundred ohms) is very small compared to the resistor R_B and may be ignored. Resistor R_B limits the no signal base-emitter current in the forward direction to approximately 100 μ amperes. The bias voltage is not developed across the base-emitter junction of the NPN junction transistor. Certain instabilities inherent in this bias method will be discussed later.

Amplification

The amplifying action is easily seen by comparing the input signal and base current with the output signal and collector current. In figure 5-9, the input signal current is assumed to be of sine waveform and of such magnitude as to vary the base current from 100μ amps (no-signal value) to zero, to 100μ amps for the first half cycle. For the second half cycle, the base current is varied from 100μ amps to 200μ amps and back to 100μ amps.

When the base current is reduced to zero, the collector current will be reduced to zero, and the collector voltage will increase to approximately 15 volts. When the base current is increased to 200μ amps, the collector current will increase to approximately 8 ma, and the collector voltage will be reduced to almost zero. Thus, the output voltage will vary sinusoidally about a no-signal value of 7.5 volts and will have a peak-to-peak value of approximately 15 volts.

CIRCUIT SIGNAL ANALYSIS

The action of a transistor amplifier will now be given with respect to the distribution of the voltages and currents through the input and output circuits before and after a signal is applied.

Figure 5-10B illustrates a transformer coupled junction transistor audio amplifier stage employing the grounded emitter as the common element between input and output circuits and a single battery for collector supply voltage and base-emitter bias. The sine waveforms of signal current and voltage are illustrated in figure 5-10A.

The circuit analysis is made for three different instants of time occurring within one complete cycle of applied signal. These instants occur when (1) $t = 0°$, (2) $t = 90°$, and (3) $t = 270°$.

At the instant when $t = 0°$, the input signal voltage is zero, and the 7.5-volt battery supplies the no-signal base-emitter bias current of 4 ma. The distribution of voltages and currents is illustrated in figure 5-10B. Only input circuits are analyzed in detail. Kirchhoff's law of voltages is applied to three closed circuits, all on the input side of the transistor. The algebraic sum of the instantaneous voltages around the three circuits is equated to zero. If the algebraic sum of the numerical values is zero, the voltages are assumed to be correct.

The first circuit to be traced starts at point A and includes the 7.5-volt battery, the bias resistor (R_B), the base (B) of the transistor, the emitter (E), and returns to the battery at the starting point (A). The circuit trace is designated as ADMNBEGA. The designation for the algebraic sum of the voltages, Σ(sum) volts = 0, identifies the individual circuit by means of the subscripts following the symbol Σ. These letters appear on the amplifier circuit (figure 5-9B, C, and D). Thus the equation that applies to

$$\Sigma \frac{\text{VOLTS}}{\text{ADMNBEGA}} = 0$$

is derived by tracing the circuit ADMNBEGA and equating the algebraic sum of the voltages equal to zero. The voltage equation for this circuit is $7.5 - 7.4 - 0.1 = 0$. The first term is the battery voltage, the second term is the drop across R_B, and the third term is the drop across the base-emitter junction.

From the equation it may be seen that the base-emitter no-signal bias current is limited principally by resistor R_B because most of the battery voltage appears across R_B. It may also be seen that the voltage drop across the base-emitter terminals of 0.1 v in the forward direction, with a base-emitter current of 100μ a or 0.1 ma, will indicate a base-emitter resistance

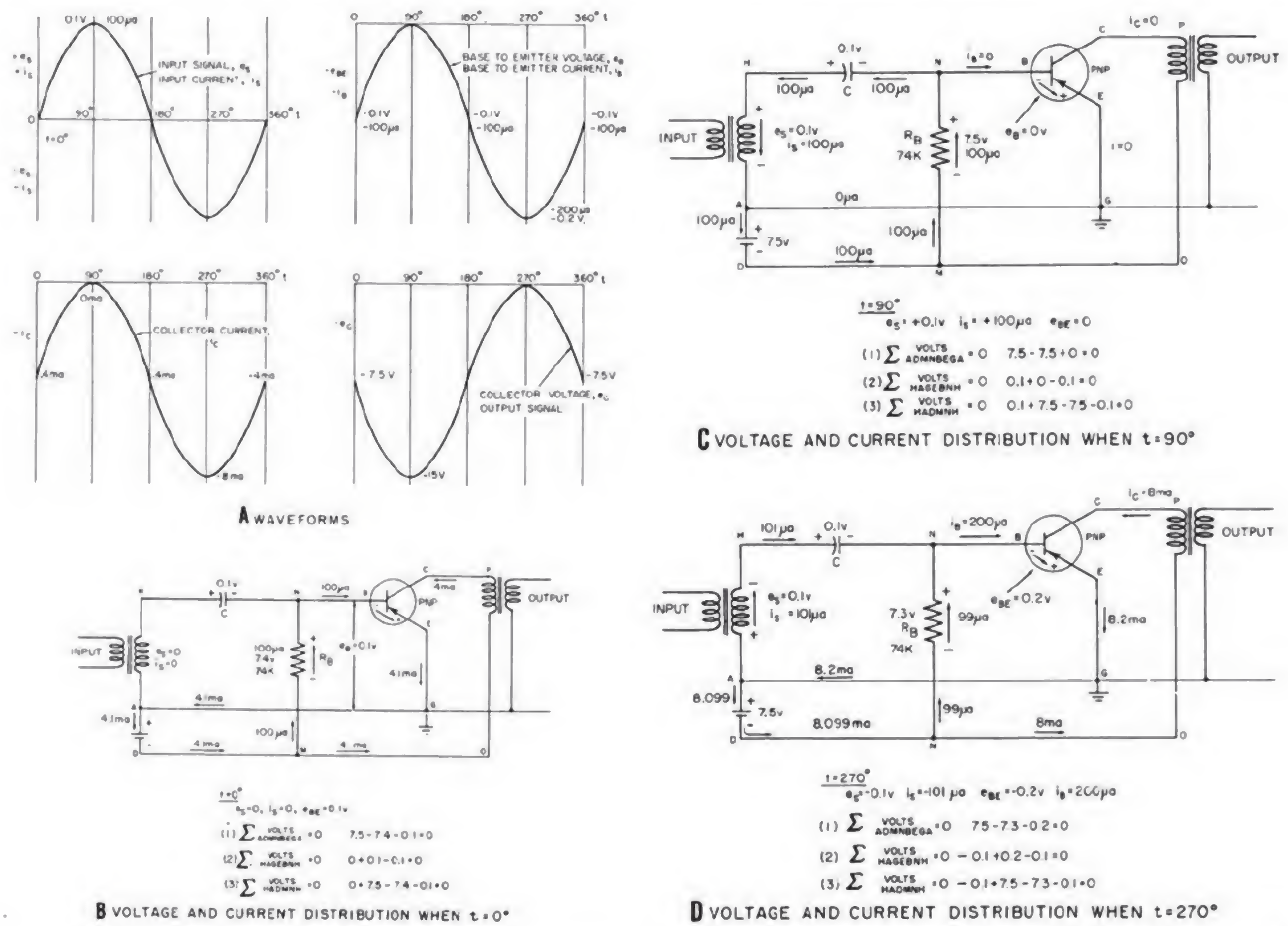

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Figure 5-10.—Circuit analysis for junction transistor amplifier having a common battery supply for input and output circuits.

of 0.1 v/0.1 ma, or 1 k-ohms. Capacitor C blocks the d-c component of voltage and current across the base-emitter junction from the secondary of the input transformer and charges up to the peak voltage drop across the junction. Capacitor Cis relatively large (2 mf), and the voltage across Cis assumed to remain at 0.1 v through the entire cycle of applied signal voltage.

The second voltage equation for the instant when t = 0° is derived by tracing around the circuit HAGEBNH and equating the algebraic sum of the instantaneous voltages to zero. Thus the equation that applies to

$$\Sigma \frac{\text{VOLTS}}{\text{HAGEBNH}} = 0$$

is 0.0 + 0.1 - 0.1 = 0. The first term is zero because at the instant t = 0° the signal voltage is zero. The second and third terms are of opposite signs indicating that the capacitor voltage is opposed by the voltage drop occurring between the base and the emitter. As stated previously, C will block the d-c component of base-emitter current and voltage from the secondary of the input transformer.

The third voltage equation for the instant when t = 0° is derived by tracing around the circuit HADMNH and equating the algebraic sum of the instantaneous voltages to zero. Thus the equation that applies to

$$\Sigma \frac{\text{VOLTS}}{\text{HADMNH}} = 0$$

0.0 + 7.5 - 7.4 - 0.1 = 0. The first term is zero because the signal voltage is zero when t = 0°. The second term is 7.5 v, representing the battery terminal voltage. The third is 7.4 v, representing the voltage drop across the bias resistor, R_B. The last term is 0.1 v, representing the voltage across C.

The no-signal condition upon which the preceding three equations depend may be regarded as the operating point B (figure 5-9) on the load line XY. The load impedance (non-inductive) is assumed to be the slope of the load line or 1875 ohms. The principal difference (other than substituting a PNP transistor for the NPN transistor) between the example of figure 5-10 and that of figure 5-9 is that the load resistor of figure 5-9 has been replaced by a transformer having negligible d-c resistance in its windings so that the collector voltage supply may be reduced from 15 v to 7.5 v without changing the slope of the load line. Thus, the non-signal collector current of 4 ma that flows through the primary of the output transformer produces a negligible d-c voltage drop across the primary, and the collector voltage for the condition is 7.5 v.

During the interval between 0° and 90°, the input signal voltage increases from 0 to a positive maximum value of 0.1 v; the input signal current increases from 0 to 100μa as represented by curve (1) of figure 5-10A. During this interval, the base-emitter current decreases from 100μa to 0, curve (2); the collector current decreases from 4 ma to 0, curve (3). At the same time, the induced voltage acting in the primary of the output transformer causes the collector voltage to increase from - 7.5 v to - 15 v, curve (4).

At the instant t = 90° (figure 5-10C) the input signal voltage is a positive maximum value of 0.1 v. The polarity of the signal voltage indicates that this voltage acts across the base-emitter junction in the backward, of high-resistance, direction; hence no base current will flow. Instead, signal current will flow through the secondary of the input transformer in series with the battery, the bias resistor R_B, and the capacitor C. The signal voltage acts in series additively with the battery voltage, thereby increasing the voltage drop across R_B from 7.4 v to 7.5 v. During the interval from 0° to 90°, the base current decreases from 100μa to 0 as the signal current increases from 0 to 100μa, indicating that approximately a constant current flows through R_B into junction N. As the current flow into the base B decreases, the current flow into the capacitor circuit NH increases. It is assumed that the capacitor is sufficiently large so that the flow of signal current through the circuit from N to H will not increase the voltage drop across the capacitor to any appreciable extent.

The voltage equation (for the instant when t = 90°) that corresponds to the designation

$$\Sigma_{\mathrm{ADMNBEGA}}^{\mathrm{VOLTS}} = 0 \text{ is } 7.5 - 7.5 - 0 = 0.$$

The slight increase in voltage across the 74 k - ohm resistor R_B from 7.4 v to 7.5 v produces a negligible increase in current through R_B and a decrease in voltage across the base-emitter junction from - 0.1 v to 0, curve (2) (figure 5-10A).

The voltage equation (for the instant when t = 90°) that corresponds to the designation

$$\Sigma_{\mathrm{HAGEBNH}}^{\mathrm{VOLTS}} = 0 \text{ is } 0.1 + 0 - 0.1 = 0.$$

The first term represents the peak positive signal voltage occurring across the secondary of the input transformer, curve (1) (figure 5-10A). The second term represents the zero voltage across the base-emitter junction, curve (2). The third term represents the constant voltage across capacitor C.

The voltage equation (for the instant when t = 90°) that corresponds to the designation

$$\Sigma_{\mathrm{HADMNH}}^{\mathrm{VOLTS}} = 0 \text{ is } 0.1 + 7.5 - 7.5 - 0.1 = 0.$$

The peak positive input signal current flows in a counterclockwise direction around the circuit.

During the interval from 90° to 180°, the input signal voltage decreases from positive maximum to 0, curve (1) (figure 5-10A). At the same time, the voltage drop across R_B decreases from 7.5 v to 7.4 v, and the base-emitter voltage increases from 0 to -0.1 v, curve (2). Thus during the first half cycle

(o° to 180°) of applied signal, the base-emitter current varies sinusoidally through a maximum change of 100 μ a.

In the collector circuit, the collector current also varies sinusoidally through a maximum change of 4 ma as the collector voltage varies sinusoidally through a maximum change of 7.5 v, curves (3) and (4).

The input signal voltage for the second half cycle is of opposite polarity to that for the first half cycle, curve (1). Thus the signal voltage opposes the battery voltage and lowers the voltage drop across R_B to 7.3 v at the instant when t = 270°. At this instant, the signal voltage acting in series addition with the capacitor voltage develops a voltage of - 0.2 v across the base-emitter junction in the forward or easy direction of current flow. Thus the base current increases to a peak of - 200μa, causing the collector current to increase to a maximum value of - 8 ma because the self-induced voltage in the output transformer primary causes the collector voltage to swing to zero, curves (3) and (4).

The voltage equation (for the instant when t = 270°) that corresponds to the designation

$$\Sigma_{ADNBBEGA}^{VOLTS} = 0 \text{ is } 7.5 - 7.3 - 0.2 = 0$$

(figure 5-9D). The current flow through R_B decreases slightly from 100μ a to 99μ a. The signal current flowing into junction N from terminal H increases from 0 to 101μa and combines with the bias current flowing through R_B into junction N to increase the base-emitter current from - 100μ a to - 200μ a, curve (2). This current returns to junction A where it divides almost equally, with 101 μ a returning to the secondary of the input transformer and 99μ a returning to the battery.

The voltage equation (for the instant when t = 270°) that corresponds to the designation

$$\Sigma_{HAGEBNH}^{VOLTS} = 0 \text{ is } - 0.1 + 0.2 - 0.1 = 0.$$

The first term of this equation represents the signal voltage, the second term represents the voltage across the emitter-base junction, and the third term represents the voltage across the capacitor.

The voltage equation (for the instant when t = 270°) that corresponds to the designation

$$\Sigma_{HADMNH}^{VOLTS} = 0 \text{ is } - 0.1 + 7.5 - 7.3 - 0.1 = 0.$$

As the voltage across R_B decreases from 7.4 v to 7.3 v, the voltage across the base-emitter junction increases from - -0.1 v to -0.2 v in the forward direction of the base-emitter circuit. The second half cycle is completed as the signal voltage decreases from negative maximum to 0, the base-emitter current decreases from - 200 to - 100μa, the collector current decreases from - 8 ma to - 4 ma, and the collector voltage swings from 0 v back to - 7.5 v.

The peak-to-peak signal voltage appearing across the primary of the output transformer is 15 v. The peak-to-peak signal component of current through the primary of the output transformer is 8 ma. The power output of the amplifier is $e_{rms}i_{rms}$, or 15/2 x 0.707 x 8/2 x 0.707 = 15 mw.

CIRCUIT ANALYSIS BY THE USE OF EQUIVALENT CIRCUITS

Circuit analysis by the use of load lines on characteristic curves is actually a d-c analysis since it is based on the static (d-c) characteristics of a transistor. This type of analysis is valuable in determining whether the circuit is biased in such a manner that the output is not distorted—that the circuit is designed so that the transistor operates on the linear portion of its characteristic curves—and that the maximum ratings of the transistor are not exceeded. For steady state a-c analysis it is necessary to use different methods; equivalent circuits of transistors are devised and used in a manner similar to that used in vacuum-tube circuit analysis.

The equivalent circuits necessary to describe transistors are somewhat more complicated than those used for vacuum tubes. (In fact, the equivalent circuit for a transistor resembles the equivalent-circuit diagram for a vacumm-tube amplifier which incorporates negative-feedback.) There are many different equivalent circuits which may be used to satisfactorily represent a transistor, each type of circuit having some features which make it desirable for circuit analysis and some features

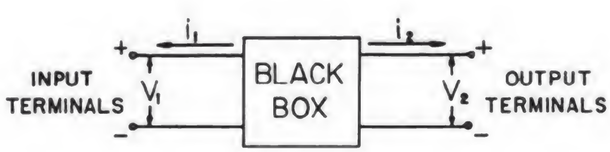
which make it undesirable. However one particular configuration, which is most often used in modern day practice, will be discussed in detail.

Development of the Equivalent Circuit

When deriving the equivalent circuits of transistor amplifiers, it is assumed that the operating point established by the bias circuits is such that the circuit is linear in operation; that is, the output signal is the same as the input signal in every respect except amplitude and possibly 180° phase difference. (As was true in vacuum-tube circuits, the assumption must be modified when considering high-frequency operation since interelectrode (junction) capacities then become significant and introduce additional effects such as phase shift.) The components used to provide bias are generally of such values that they may be ignored when actually making circuit computations. The foregoing fact will be pointed out later in the chapter when a numerical example of circuit computations is presented.

The Black Box

To develop the equivalent circuit of any circuit component, it is a common procedure to treat the device as a "black box" with two terminal pairs—input and output. The only information available from the black box is in the form of external, measurable quantities—input and output currents and voltages. The black box representation of a circuit is illustrated in figure 5-11. The equivalent circuit



25.76

Figure 5-11.—Black box representation of a circuit.

is developed by examining the equations which relate the four variable voltages and currents. Network theory states that a "black box" containing a linear network can be described by two equations which express the relationship of two of the variables (called the dependent variables) in terms of the other two variables (called the independent variables) and four constants or parameters. When the black box contains a transistor, the parameters are electrical characteristics which are associated with the particular transistor in use. Four parameters are electrical characteristics which are associated with the particular transistor in use. Four parameters are required. For a vacuum tube, three inter-related parameters were used in developing the equivalent circuit—μ, g_m, and r_p.

The Equations

The choice as to which variables are dependent and which are independent is arbitrary. Each different choice results in a different equivalent circuit. The choice which is most frequently used for transistors is defined by the following general equations:

$$v_1 = h_{11} i_1 + h_{12} v_2$$
$$i_2 = h_{21} i_1 + h_{22} v_2$$

The input voltage and output current, v_1 and i_2, are chosen as the dependent variables; input current and output voltage, i_1 and v_2, are the independent variables; the h's are the parameters. The voltages and currents are a-c signals. The physical meanings and dimensions of the parameters determined by these equations are as follows:

$$h_{11} = \frac{v_1}{i_1} \text{ with } v_2 = 0$$

$$h_{12} = \frac{v_1}{v_2} \text{ with } i_1 = 0$$

$$h_{21} = \frac{i_2}{i_1} \text{ with } v_2 = 0$$

$$h_{22} = \frac{i_2}{v_2} \text{ with } i_1 = 0$$

The first two parameters are determined by the equation $v_1 = h_{11} i_1 + h_{12} v_2$; the second two parameters are determined by the equation $i_2 = h_{21} i_1 + h_{22} v_2$. Therefore, h_{11} is the input impedance with the output a-c short circuited and has dimensions of ohms; h_{12} is

the reverse voltage transfer ration (a feedback constant) with the input a-c open circuited and is dimensionless; h_{21} is the forward current transfer ratio (a gain constant) with the output a-c short circuited and is dimensionless; h_{22} is the output admittance with the input a-c open circuited and has dimensions of mhos. Certain choices of variables will result in parameters which all have the same dimensions; however the particular choice described above results in parameters with mixed dimensions, referred to as "hybrid" parameters and designated by the letter h.

The Equivalent Circuit

Once the equations relating the variables have been written, an equivalent circuit can be devised which will perform in the manner described by the equations. The equivalent circuit for the hybrid-parameter equations written above is shown in figure 5-12. The type of

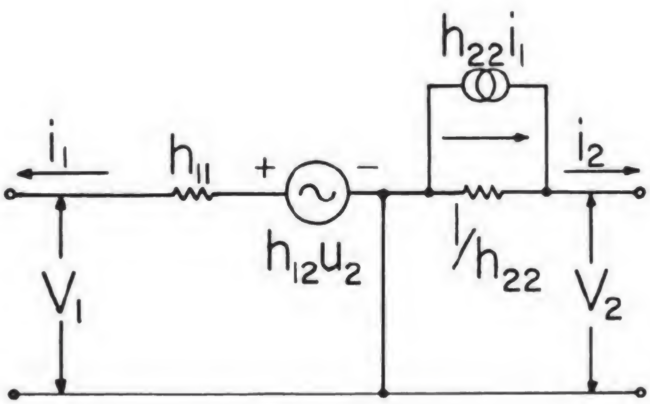


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Figure 5-12.—Equivalent circuit of the "black-box."

components used in the equivalent circuit are determined by the dimensions of the parameters; the magnitude of the components is determined by the magnitude of the parameters.

When specifying the characteristics of transistors, the parameters are usually given subscripts different from those used in the equations of the previous paragraphs. The subscripts used for transistor characteristics are two

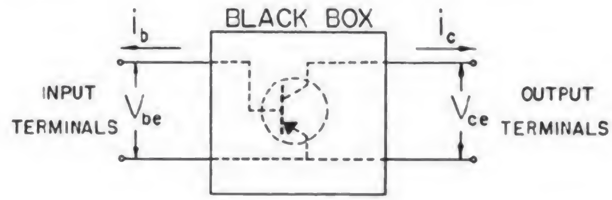

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Figure 5-13.—Black-box containing a transistor with common-emitter arrangement.

letters. The first subscript letter is given meaning as follows:

$$h_i = h_{11} \qquad h_f = h_{21}$$
$$h_r = h_{12} \qquad h_o = h_{22}$$

The second subscript letter denotes the arrangement of the transistor in the circuit. For example, if the emitter lead is common to both the input and output, the second subscript letter is designated as e. The four parameters for the arrangements are then h_{ie}, h_{re}, h_{fe}, and h_{oe}. The use of letter subscripts will be illustrated further when defining the parameters as they pertain to figure 5-13.

Transistor Parameters and Equivalent Circuits

Figure 5-13 shows the "black box" containing a transistor which has its emitter lead common to input and output terminals. The voltage and current subscripts are self-explanatory (e.g., v_{ce} is collector to emitter voltage). The equations for this black box are:

$$v_{be} = h_{ie}\, i_b + h_{re}\, v_{ce}$$
$$i_c = h_{fe}\, i_b + h_{oe}\, v_{ce}$$

The equivalent circuit for these equations, and thus the equivalent circuit for the grounded- or common-emitter transistor, is shown in figure 5-14.

Figures 5-15 and 5-16 illustrate the imaginary black boxes, the equations, and the resulting equivalent circuits for the common-base and common-collector arrangements. Notice that the equations which describe these arrangements and the resulting equivalent circuits of each arrangement are similar to the corresponding equations and circuits for the

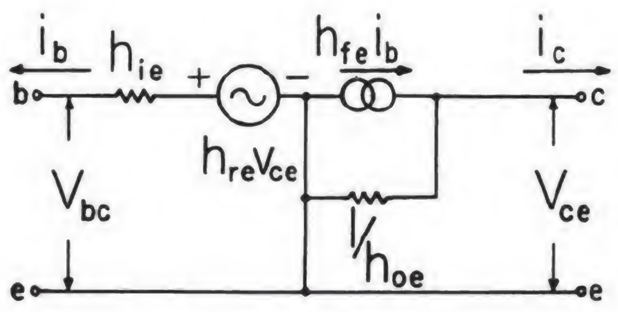
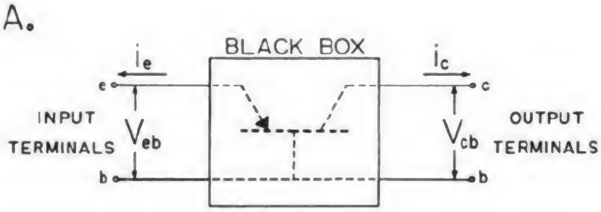


Figure 5-14.—Equivalent circuit for a common-emitter transistor.

common-emitter arrangement. Only the subscripts are different in appearance. The numerical values for the parameters of each arrangement are very different, however. There are mathematical relationships between the parameters for each arrangement of a given transistor. The relationships will not be derived in this training course but are presented in the form of a conversion table in table 5-3.

A.



B. THE EQUATIONS

$$V_{eb} = h_{ib} i_e + h_{rb} V_{cb}$$

$$i_c = h_{fb} i_e + h_{ob} V_{cb}$$

C. THE EQUIVALENT CIRCUIT

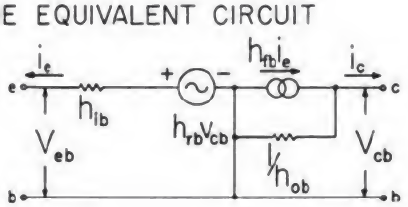


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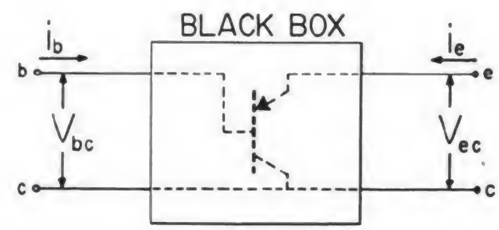
Figure 5-15.—The common-base arrangement.

Table 5-4 presents a set of values for the hybrid parameters of a typical transistor. Actually, parameter values vary widely for a given arrangement, depending on the transistor type and operating point. However, table 5-4 is useful in pointing out the relative magnitude of parameter values among the three arrangements possible with a single transistor.

A.



B. THE EQUATIONS

$$V_{bc} = h_{ic} i_b + h_{rc} V_{ec}$$

$$i_c = h_{fc} i_b + h_{oc} V_{ec}$$

C. THE EQUIVALENT CIRCUIT

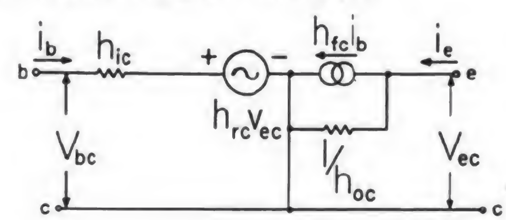


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Figure 5-16.—Equivalent circuit for a common-emitter transistor.

Derivation of Circuit Equations

The a-c circuit of a common-emitter audio amplifier is shown in figure 5-17, together with its equivalent circuit. The equivalent circuit will be used to derive the ordinary circuit equations of current gain, voltage gain, power gain, input resistance, and output resistance.

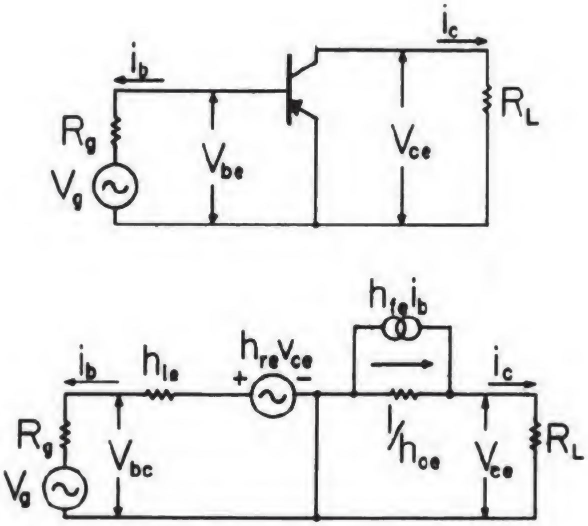

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Figure 5-17.—Common-emitter amplifier and its equivalent circuit.

CURRENT GAIN.—By definition the current gain of the circuit shown will be the ratio of collector current to base current:

$$Ai = \frac{-i_c}{i_b}$$

(The negative sign appears because of the direction in which currents have been assumed; i_b is a clockwise current, whereas i_c is counterclockwise.) Using Kirchhoff's current law at the collector terminals, the following equation can be written:

$$i_c = h_{fe}\, i_b + h_{oe}\, v_{ce}$$

By Ohm's law the expression $v_{ce} = i_c\, R_L$ is derived. Substituting this expression in the current equation yields:

$$i_c = h_{fe}\, i_b - h_{oe}\, i_c\, R_L$$

or, by rearranging terms and factoring i_c,

$$i_c\,(1 + h_{oe}\, R_L) = h_{fe}\, i_b$$

Solving for current gain, $A_1 = -i_c/i_b$

$$= \frac{-h_{fe}}{1 + h_{oe}\, R_L}$$

VOLTAGE GAIN.—The definition of the voltage gain of the circuit shown in figure 5-17 is $A_v + \frac{v_{ce}}{v_{be}}$. The derivation begins with the current equation at the collector terminal,

$$i_c = h_{fe}\, i_b + h_{oe}\, v_{ce}.$$

Next, Kirchhoff's voltage equation for the left-hand loop of the equivalent circuit is written. Since we are interested in the gain from the base terminal to the collector terminal, the voltage of the generator and the voltage drop across the generator resistance are taken together as v_{be}.

$$v_{be} = i_b\, h_{ie} + h_{re}\, v_{ce}$$

Solving for i_b: $\quad i_b = \frac{v_{be}}{h_{ie}} - \frac{h_{re}\, v_{ce}}{h_{ie}}$

Using Ohm's law for the load, $i_c = \frac{-v_{ce}}{R_L}$

The derived expressions for i_c and i_b are then substituted in the current equation to give:

$$\frac{-v_{ce}}{R_L} = h_{fe}\left(\frac{v_{be}}{h_{ie}} - \frac{h_{re}\, v_{ce}}{h_{ie}}\right) + h_{oe}\, v_{ce}$$

Expanding, rearranging terms and factoring v_{ce} gives:

$$\left(\frac{h_{fe}\, h_{re}}{h_{ie}} - h_{oe} - \frac{1}{R_L}\right) v_{ce} = \frac{h_{fe}\, v_{be}}{h_{ie}}$$

Solving for gain:

$$A_v = \frac{v_{ce}}{v_{be}} \equiv \frac{\frac{h_{fe}}{}}{h_{ie}\left(\frac{h_{fe}h_{re}}{h_{ie}} - h_{oe} - \frac{1}{R_L}\right)}$$

This expression is usually rearranged to the following form:

$$A_v = \frac{-h_{fe}\, R_L}{h_{ie} + R_L\,(h_{oe}\, h_{ie} - h_{fe}\, h_{re})}$$

Table 5-3.—H-Parameter Conversion Formulas.

h - PARAMETER CONVERSION FORMULAS			
FROM CE TO CB	FROM CE TO CC	FROM CB TO CE	FROM CB TO CC
$h_{ib} = \dfrac{h_{ie}}{1 + h_{fe}}$	$h_{ic} = h_{ie}$	$h_{ie} = \dfrac{h_{ib}}{1 + h_{fb}}$	$h_{ic} = \dfrac{h_{ib}}{1 + h_{fb}}$
$h_{rb} = \dfrac{h_{ie} h_{oe}}{1 + h_{fe}} - h_{re}$	$h_{rc} = 1 - h_{re} \approx 1$	$h_{re} = \dfrac{h_{ib} h_{ob}}{1 + h_{fb}} - h_{rb}$	$h_{rc} = \dfrac{h_{ib} h_{ob}}{1 + h_{fb}} + h_{rb} \approx 1$
$h_{fb} = \dfrac{-h_{fe}}{1 + h_{fe}}$	$h_{fc} = -(1 + h_{fe})$	$h_{fe} = \dfrac{-h_{fb}}{1 + h_{fb}}$	$h_{fc} = \dfrac{-1}{1 + h_{fb}}$
$h_{ob} = \dfrac{h_{oe}}{1 + h_{fe}}$	$h_{oc} = h_{oe}$	$h_{oe} = \dfrac{h_{ob}}{1 + h_{fb}}$	$h_{oc} = \dfrac{h_{ob}}{1 + h_{fb}}$

The input and output signals, v_{be} and v_{ce}, were assumed to be of the same polarity. However, a positive going signal at the base v_{be} will actually cause a negative going signal at the collector v_{ce}. Hence the negative sign results on the expression for gain.

POWER GAIN.—Power gain is defined as the ratio of the power delivered to the load divided by the power delivered to the input:

$$G = \frac{i_c \, v_{ce}}{i_b \, v_{be}} = \left(\frac{i_c}{i_b}\right) x \left(\frac{v_{ce}}{v_{ce}}\right)$$

Thus, we can see that the power gain is the product of current gain and voltage gain, and the power gain can be expressed as this product without further derivation.

$$G = (A_i) \times (A_v) = \frac{h_{fe}^{\ 2} \, R_L}{(1 + h_{oe} \, R_L) \left[h_{ie} + R_L \, (h_{oe} \, h_{ie} - h_{fe} \, h_{re})\right]}$$

INPUT RESISTANCE.—Input resistance by definition is $r_i = \dfrac{v_1}{i_1}$. The derivation begins with the equation for current at the collector terminal:

$$i_c = h_{fe} i_b + h_{oe} v_{ce}$$

Substitution of the Ohm's law solution for current in the load, $i_c = \dfrac{-v_{ce}}{R_L}$ into the equation

Table 5-4.—Hybrid Parameter Values for a Typical Transistor.

COMMON EMITTER	COMMON BASE	COMMON COLLECTOR
h_{ie} = 1950 ohms	h_{ib} = 39 ohms	h_{ic} = 1950 ohms
$h_{re} = 575 \times 10^{-6}$	$h_{rb} = 380 \times 10^{-6}$	$h_{rc} = 1$
$h_{fe} = 49$	$h_{fb} = 0.98$	$h_{fc} = -50$
h_{oe} = 24.5 u mhos	h_{ob} = 0.49 u mhos	h_{oc} = 24.5 u mhos

for collector current yields:

$$\frac{-v_{ce}}{R_L} = h_{fe}\, i_b + h_{oe}\, v_{ce}$$

Rearranging and solving for v_{ce} gives:

$$v_{ce} = \frac{-h_{fe}\, i_b}{1/R_L + h_{oe}}$$

Substituting the foregoing expression into the equation for base voltage, $v_{be} = h_{ie}i_b + h_{re}v_{ce}$

$$\left[h_{ie} - \frac{h_{re}\, h_{fe}}{1/R_L + h_{oe}}\right]$$

Expanding and rearranging gives the following expression for input resistance:

$$r_i = \frac{h_{ie} + (h_{oe}\, h_{ie} - h_{fe}\, h_{re})\, R_L}{1 + h_{oe}\, R_L}$$

OUTPUT RESISTANCE.—The technique used in determining the output resistance of an amplifier is to put the signal source in the input circuit to zero and then determine the resistance as seen when looking back into the amplifier output terminals. Another way of stating the same technique is to consider the voltage generator of the signal source in the input circuit to be short circuited and the load resistance to be removed. In order to see the technique more clearly, the equivalent circuit is redrawn in figure 5-18 as it is used to determine output resistance. Notice that the internal resistance of the signal source in the generator remains in the circuit; only the voltage of the signal source is put to zero.

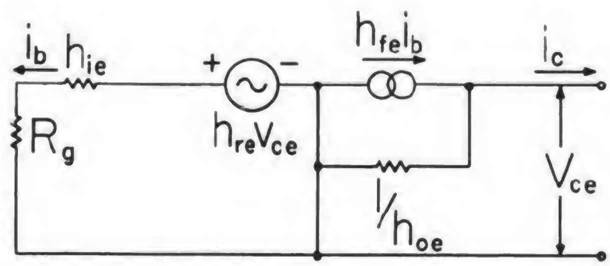

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Figure 5-18.—An equivalent circuit arrangement to determine output resistance.

Looking at figure 5-18 it can be seen that the output resistance is given by the expression $r_o = v_{ce}/i_c$.

The derivation begins by writing the loop current equation for the left-hand loop of the equivalent circuit,

$$i_b\,(R_g + h_{ie}) - h_{re}\, v_{ce} = 0$$

Solving for i_b.

$$i_b = \frac{-h_{re}\, v_{ce}}{h_{ie} + R_g}$$

The expression for i_b is substituted in the current equation for the collector terminal, $i_c = h_{fe}\, i_b + h_{oe}\, v_{ce}$, to give

$$i_c = \frac{-h_{fe}\, h_{re}\, v_{ce}}{h_{ie} + R_g} + h_{oe}\, v_{ce}$$

Rearranging and solving for r_o gives:

$$r_o = \frac{h_{ie} + R_g}{h_{oe}\, h_{ie} - h_{fe}\, h_{re} + h_{oc}\, R_g}$$

A Numerical Example Using Hybrid Parameters

Figure 5-19A shows an amplifier driven by a signal source (v_g) which has an internal resistance of R_g. Capacitor C1 blocks the d-c bias voltage from the signal source and couples the signal to the base of the transistor. Resistors R1 and R2 establish the base-emitter forward bias. Resistor R3 provides temperature stabilization, and capacitor C2 bypasses the a-c signal current around resistor R3. Capacitor C3 blocks the d-c collector voltage from and couples the output signal to the following stage.

Assume it is desired to calculate current gain, voltage gain, power gain, input resistance, and output resistance for the amplifier. The first step is to redraw the circuit, removing the components which will not enter into the calculations. These components are the low-impedance coupling capacitors, the high-resistance bias circuit, and the low-impedance temperature compensation circuit in the emitter lead. The resulting circuit is shown in figure 5-19B.

The next step is to redraw the circuit, replacing the transistor with its equivalent circuit as shown in figure 5-19C, and to obtain the values of the hybrid parameters from the specifications and data sheet for the transistor.

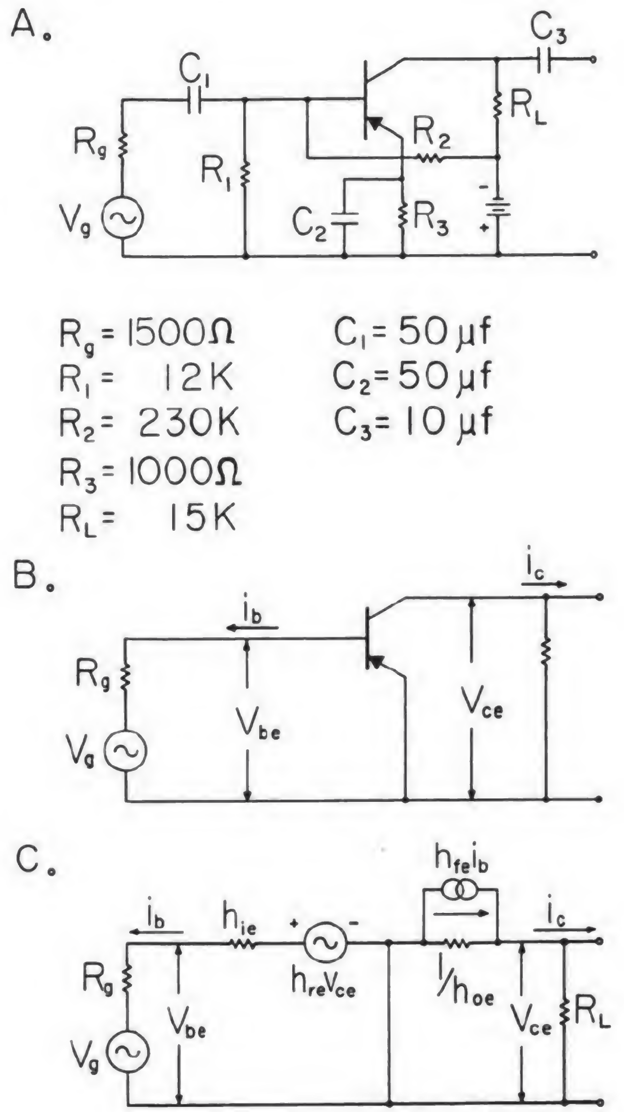

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Figure 5-19.—Common-emitter amplifier and its preparation for analysis.

For the chosen operating point (emitter current of 1 ma and collector-emitter voltage of 8 volts) the parameters for the transistor in figure 5-19 are: h_{ie} = 1500 ohms, $h_{re} = 5 \times 10^{-4}$, $h_{fe} = 50$, $h_{oe} = 20 \times 10^{-6}$ mhos.

The equivalent circuit of figure 5-19 is the same as that used in deriving the formulas of the preceding section. Therefore, the desired calculations may be made by substituting the

proper values for the parameters and circuit components in the derived equations.

CURRENT GAIN.—

$$A_i = -\frac{h_{fe}}{h_{oe}R_L + 1}$$

$$= \frac{-50}{(20 \times 10^{-6})(15 \times 10^3) + 1}$$

$$= \frac{-50}{1.3}$$

$$= -38.4$$

The answer indicates that the input current is amplified 38.4 times and is reversed 180° in phase when going through the transistor.

VOLTAGE GAIN.—

$$A_v = \frac{-h_{fe}R_L}{(h_{ie}h_{oe} - h_{fe}h_{re})R_L + h_{ie}}$$

$$= \frac{-50 \times 15,000}{(1500 \times 20 \times 10^{-6} - 50 \times 5 \times 10^{-4})15,000 + 1500}$$

$$= \frac{-75 \times 10^4}{1575}$$

$$= -476$$

The answer indicates that the input voltage is amplified 476 times and is reversed 180° in phase when going through the transistor.

POWER GAIN.—It is more convenient to use the relationship $G = (A_i) \times (A_v)$ than to use the gain formula. Therefore: $G = (-38.4)(-476) = 18{,}278$ or, converting to decibels, $G = 10 \log_{10} 18{,}278 = 10 \times 4.26 = 42.6$ db

INPUT RESISTANCE.—

$$r_i = \frac{h_{ie} + (h_{oe}h_{ie} - h_{fe}h_{re})R_L}{1 + h_{oe}R_L}$$

$$r_i = \frac{1500 + (20 \times 10^{-6} \times 1500 - 50 \times 5 \times 10^{-4})15,000}{1 + 20 \times 10^{-6} \times 15,000}$$

$$= \frac{1575}{1.3}$$

$$= 1212\Omega$$

OUTPUT RESISTANCE.—

$$r_o = \frac{h_{ie} + R_g}{h_{oe}h_{ie} - h_{fe}h_{re} + h_{oe}R_g}$$

$$= \frac{1500 + 1500}{20 \times 10^{-6} \times 1500 - 5 \times 10^{-4} \times 50 + 20 \times 10^{-6} \times 1500}$$

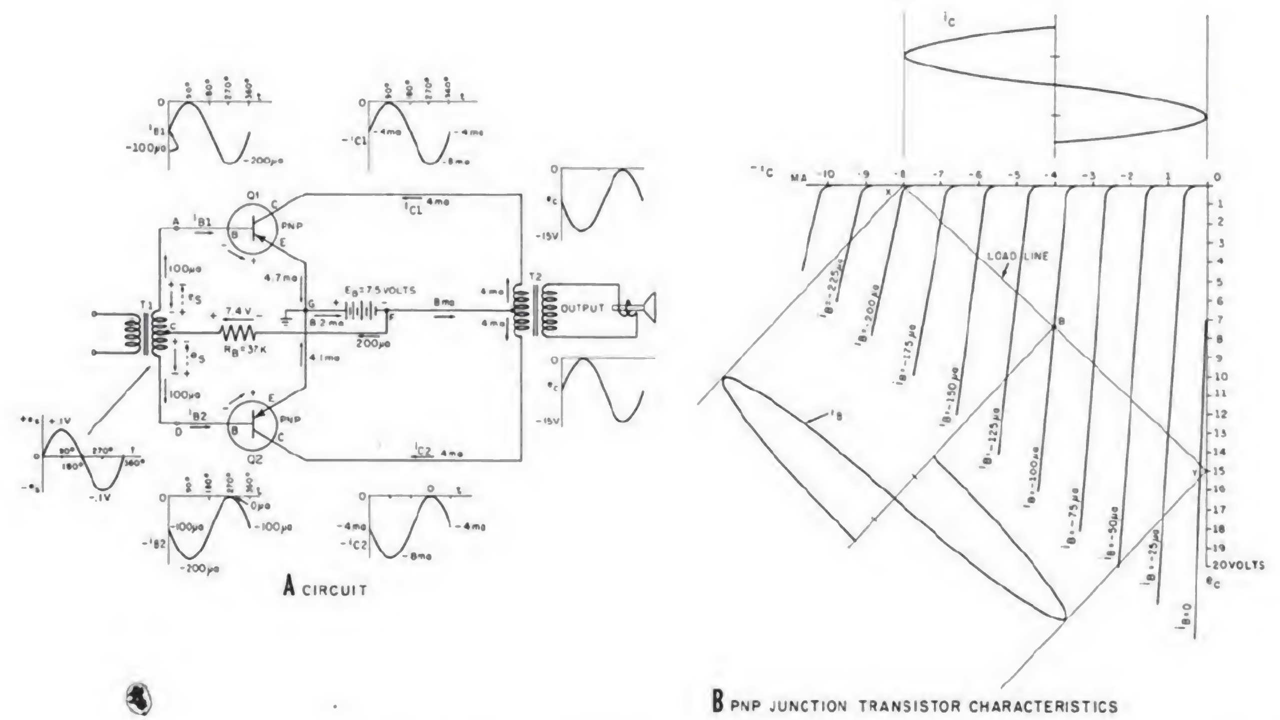
$$= \frac{3,000}{0.035}$$

$$= 85,714\Omega$$

TRANSISTORS IN PUSH PULL

Transistor power amplifiers are usually connected in push pull because of the advantages over single-ended operation. The most important advantages are the reduction in distortion and the removal of d-c core saturation from the output transformer. Second harmonic distortion and other distortion caused by even-order harmonics are cancelled in push-pull class A amplifiers. The load impedance and the output power are twice the values for single-ended operation. The incremental inductance of the output transformer is also higher than for single-ended operation as a result of the elimination of the d-c component of primary current.

A class-A push-pull amplifier using PNP transistors is illustrated in figure 5-20A. The characteristic curves for these transistors are illustrated in figure 5-20B. When biased for class-A operation, the no-signal collector current is 4 ma (point B on the load line). The corresponding base current is 100 μa. The voltage across the bias resistor R_B is the difference between the battery voltage and the drop across the base-emitter circuit, or 7.5 - 0.1 = 7.4 v. The no-signal base-emitter current through R_B is the sum of the base-emitter current supplied to each transistor, or 200 ma.



20.172

Figure 5-20.—Transistor push-pull amplifier.

The resistance of R_B is $7.4/200 \times 10^{-6}$ = 37,000 ohms.

Consider the action of the input signal on the base-emitter current of each transistor. When t = o°, the input signal is 0; the base-emitter current through R_B divides at C, flowing in opposite directions through the two halves of the secondary of T1.

When t = 90°, the signal voltage has a peak value of 0.2 v, and the direction is represented by the solid arrows. The signal voltage is distributed equally between both halves of the secondary of T1 with 0.1 v action in each half. By tracing around the input circuit of TR1, GFCABEG, the voltage equation is developed. By Kirchhoff's law of voltages, $\Sigma^{\text{VOLTS}}_{\text{GFCABEG}}$ = 0, and the corresponding equation is 7.5 - 7.4 - 0.1 - 0 = 0. The first term of this equation represents the battery voltage, the second term represents the drop across R_B, the third term represents the signal voltage across the upper half of the secondary of T1, and the fourth term represents the drop across the base-emitter circuit of TR1. At this instant (t = 90°), the signal voltage induced in the upper half of the secondary of T1 opposes the flow of base-emitter current in TR1, and the base current of TR1 is 0.

At the same instant, the signal voltage induced in the lower half of the secondary of T1 aids the flow of base-emitter current in TR2. The voltage equation corresponding to the designation $\Sigma^{\text{VOLTS}}_{\text{GFCDBEG}}$ = 0 is 7.5 - 7.4 + 0.1 - 0.2 = 0. The first term represents the battery voltage, the second term represents the drop across R_B, the third term represents the voltage induced in the lower half of the secondary of T1, and the fourth term represents the drop across the base-emitter circuit of TR2. At this instant (t = 90°), the base-emitter current of TR2 is 200μa.

One-half cycle later, when t = 270°, the polarities of the signal voltage are reversed as indicated by the dotted arrows in the secondary of T1. At this instant, the voltage in the upper half of the secondary of T1 aids the base-emitter bias voltage of TR1, and the base current of TR1 increases to 200μa. At the same instant,

the voltage in the lower half of the secondary of T1 opposes the base-emitter bias of TR2, and the base current of TR2 decreases to 0. For the upper circuit, GFCABEG, $\Sigma^{VOLTS}_{GFCABEG} = 0$, and the voltage equation is $7.5 - 7.4 + 0.1 - 0.2 = 0$. For the lower circuit, GFCDBEG,$\Sigma^{VOLTS}_{GFCDBEG} = 0$, and the voltage equation is $7.5 - 7.4 - 0.1 - 0 = 0$. From the fourth term in these equations, the voltage drop across the base-emitter terminals of the transistors is 0.2 v for TR1 and 0.0 v for TR2. Thus the base-emitter current of TR1 has increased to 200 μa while that of TR2 has decreased to 0.

The current through RB remains constant over the input cycle; hence the voltage drop across R_B is constant, and R_B does not require a bypass capacitor when the amplifier is operated class A.

The waveform of current in the collector circuits of TR1 and TR2 is like that of the input circuits. On no-signal, the collector currents flow in opposite directions through the primary of T2 from the center tap. Because these currents are equal in magnitude, the ampere turns are equal. Because they are opposite in direction, they produce no effect on the magnetization of the iron, and there is no magnetization of the core when the input signal is 0. When the input signal current increases the collector current of TR2 from 4 ma to 8 ma, it decreases the collector current of TR1 from 4 ma to 0. The increasing current in the lower half of the primary of T2 and the decreasing current in the upper half combine additively in the secondary to produce the output voltage of T2. Similarly, on the next half cycle, the increasing current in the upper half of the primary of T2 and the decreasing current in the lower half combine additively in the secondary. The effect is the same as that of combining the output signal voltages of TR1 and TR2 in series addition across the two halves of the primary of T2. Thus the TR1 output signal voltage of 15 v (peak-to-peak) combines effectively in series addition with the TR2 output signal voltage of 15 v (peak-to-peak) to produce a peak-to-peak output voltage of 30 v. The peak-to-peak signal current through the primary of T2 is 8 ma. Thus the effective impedance looking into the primary of T2 is $30/0.008 = 3750$ ohms. The power output is $e_{rms}i_{rms} = 30/2 \times 0.707 \times 8/2 \times 0.707$ 30 mw. The value of power output is twice that of the example of figure 5-10 in which a single-ended amplifier employs a transistor of the same characteristics as those of the push-pull stage.

TRANSISTOR SWITCHING CIRCUITS

Pulse and switching circuits are used in radar, television, telemetering, pulse modulation communications, and computers. The recent advent of high-speed digital computers has, to a large extent, been due to the fact that transistors are readily adaptable as extremely efficient, low-power electronic switches. The following discussion will explain the general principles of transistor switching.

Figure 5-21 shows a simple switching circuit. At a first glance it would appear that the circuit is a common-emitter amplifier. However, the circuit shown in figure 5-21 does not amplify in the ordinary sense. It serves as an electric switch which has two conditions-on and off-just as a mechanical switch. For convenience in explanation, the input circuit is shown as a physical switch. In most equipment, the input would actually come from other electrical circuits; in many cases, the input would come from the output of a similar electronic switch. In all cases, transistor switching circuits are designed to receive an input signal instantaneously having one of two conditions. One input signal condition results in turning the transistor switch on and the other signal condition turns the switch off.

The transistor of the switching circuit shown in figure 5-21 is of the PNP type. With the switch in position 2 (as shown), the two junctions are both reverse biased. When reverse bias exists, the transistor is said to be operating in the "cutoff region." The only currents flowing in the circuits when the transistor is cut off are the leakage currents, which are small enough to be neglected in a generalized

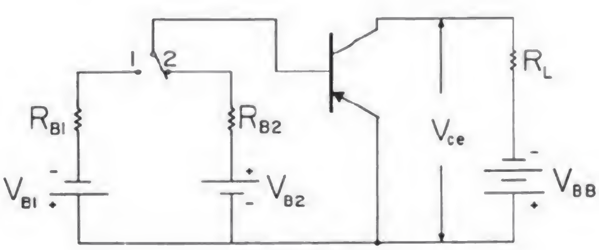


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Figure 5-21.—A transistorized electronic switching circuit.

analysis of circuit operation. When the transistor is cut off, the collector voltage v_{ce} is essentially the same as the collector supply voltage V_{BB}. Because only a negligible amount of current is flowing in the collector circuit (only the leakage), there is no significant voltage drop across the resistance R_L.

When the switch is in position 1, the emitter-base circuit is forward biased and the transistor will conduct. The resistance in the base circuit R_{B1} is usually chosen so that the transistor will conduct a large amount of current (which requires a large base current), thus making the voltage drop across the resistor R_L essentially equal to the collector supply voltage and the voltage v_{ce} essentially zero. When the described condition exists, the transistor is operating in or near its "saturation region."

By definition a transistor is operating in the region of saturation when both junctions are forward biased. To illustrate what happens during saturation, consider the switch in the base circuit of figure 5-21 to be in position 1, and consider the resistor R_{B1} to be a variable resistance. First assume R_{B1} to be of such a value that the transistor will be operating in its linear portion, just as though the circuit were an ordinary class-A amplifier. If R_{B1} is decreased, more base current will be drawn. As base current increases, collector current also increases, thereby increasing the voltage drop across the resistance R_L. If R_{B1} is decreased further, the voltage v_{ce} approaches zero. As the voltage v_{ce} approaches zero, a condition is reached where it no longer changes nor does the collector current change with an increase in base current. The value of collector-to-emitter voltage when this condition exists is called the collector-to-emitter saturation voltage. The collector-to-emitter saturation voltage is small, however, and when it is reached, the base is actually more negative than the collector. Thus, the collector-base junction is forward biased as is the emitter-base junction. For a given transistor, the collector-to-emitter saturation voltage is dependent on the base current for a specified collector current, but in all cases is small since it essentially represents the voltage drop across a forward-biased junction. The transistor can, therefore, conduct large values of current without significant collector dissipation, thereby performing as an efficient electron switch.

In analyzing the operation of the transistor switching circuit of figure 5-21, changing the switch from position 2 to position 1 amounts to the application of a negative voltage step signal in the base circuit. Returning the switch to position 1 amounts to the application of a positive step voltage signal. If we consider switching from position 2 to position 1 and then back to position 2 as one cycle, the cycle essentially represents the application of negative pulse in the base circuit. Furthermore, this pulse has ideal characteristics—zero rise and fall time. Examining the output (v_{ce}) which results from such a negative pulse input, it is found that the output will be a positive pulse, but it will not have ideal characteristics—zero rise and fall time. A finite amount of time is required to turn the transistor on (cause it to begin conduction), and a finite amount of time is required to cut the transistor off. The rise and fall time is caused, in part, by the characteristics of the transistor and, in part, by the design of the circuit.

If the transistor is operating in the saturation region, an additional delay results when switching the transistor from the saturated condition to the cutoff condition. This delay, known as storage time, is due to the fact that when a transistor is in the saturated condition both the collector and emitter are injecting minority carriers into the base region. When the base signal changes, these minority carriers cannot be instantaneously removed from the base region. During the period of time that these "stored" minority carriers are being removed from the base region, the collector continues to conduct, resulting in an apparent delay in collector response to the signal at the base. Because this delay is often undesirable, most circuits are designed in a manner which either prevents the transistor from going into saturation or prevents it from operating deeply in the saturation region.

ZENER DIODE

The Zener diode, commonly called a breakdown diode, is a welcome newcomer to electronics. Its principal uses are voltage regulation, surge protection, arc suppression, coupling, biasing, and switching.

Zener diodes are available over a wide range of voltage and power levels, as compared to the VR tube which is limited in these respects. A comparison between the two will be made

later. The Zener diode is unique among semiconductors in that its rectifying junction operates at a reverse bias condition. Special diffusion techniques are applied in the formation of the junction to create the required reverse bias properties. When the rectifying junction is back-biased above the junction breakdown voltage, the Zener knee and constant voltage plateau that characterize the Zener operating curve are obtained.

In the forward-biased diode (figure 5-22), the P region is made more positive than the N region. The polarity causes the holes in the P region and the electrons in the N region to be pressed against the potential barrier, thereby decreasing the barrier's width and lowering its resistance. When the PN junction is reverse biased, figure 5-22B, the positive holes (P material) and the free electrons (N material) are attracted away from the potential barrier, increasing its effective width and its resistance to current flow.

Semiconductor materials are never perfect. There are always a few free electrons in the P material and a few free holes in the N material. Thermal agitation will produce even more free electrons and holes, which are minor current carriers. These carriers cause a small current to flow in the back-biased condition. The extremely small current is called reverse current and tends to remain at an almost constant value at all voltages up to the junction breakdown voltage.

As the reverse voltage is increased to the critical point and beyond (figure 5-23), current conduction across the potential barrier increases very rapidly. The transition from nonconduction to conduction is very sharp and well defined in a Zener diode. The transition point on the characteristic curve is called the Zener knee.

At applied voltages greater than the breakdown point, the voltage drop across the diode junction becomes essentially constant for a wide range of currents, creating the Zener control region. The reverse conductance and nearly constant voltage drop are the results of an avalanche current multiplication in the potential barrier.

The avalanche, in simple terms, can be thought of as a process of electron multiplication by collision. A schematic representation of the process is shown in figure 5-22C. In this process, a free electron in the P material receives enough energy from the applied field across the potential barrier to accelerate it sufficiently so that when it collides with a fixed electron it can knock it free. The pair of electrons is again accelerated until each collides with two more electrons, resulting in four electrons which are accelerated, and so on. The current multiplication process continues on with higher applied voltages. However, the voltage across the barrier does not increase substantially, since the energy of the avalanche electrons is limited by the critical impact velocity.

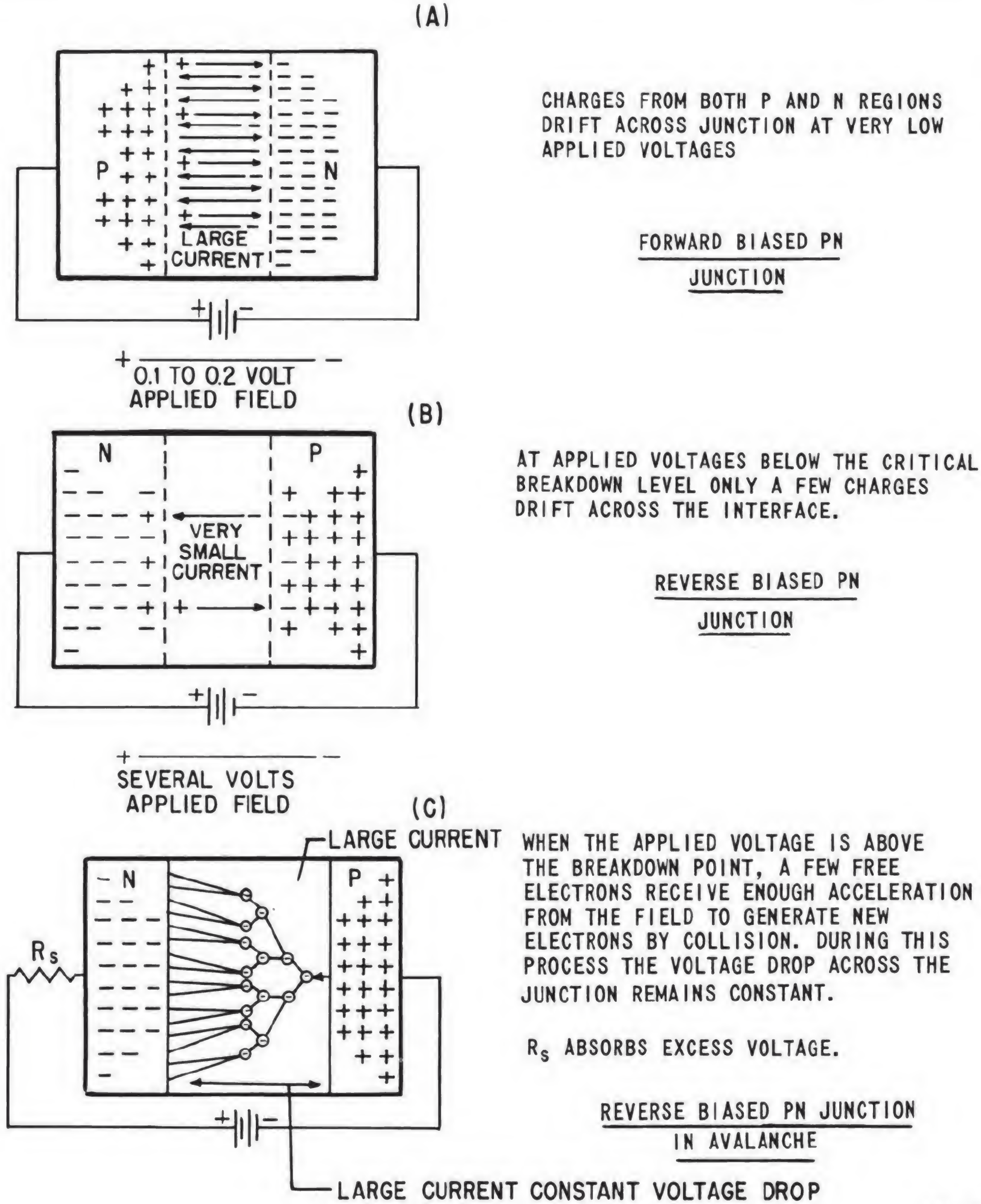
The constant voltage condition across the diode junction implies that there must be a resistive element somewhere in the circuit across which the applied voltage can drop to the constant level. The ballast element may be a passive resistance element (resistor), an active resistance element (transistor), a capacitive reactance (capacitor), or an inductive reactance (inductor).

The voltage level at which breakdown occurs is closely controlled by the impurity concentrations and gradients introduced into the semiconductor material. The special semiconductor diffusion techniques insure a very close control of the important Yener diode parameter as well as the associated limits and tolerances.

Figure 5-23 is typical of all types of Zener diodes. It shows that the Zener diode can conduct current in both directions. The fact that the forward current I_F is a function of forward voltage V_F is essentially the same for all used in some applications. V_Z is the nominal Zener voltage which may range from 6.8 to 200 volts, depending on the type of diode. The Zener knee is represented by a sharp break from virtual nonconduction to conductance at the nominal Zener voltage V_Z. The minimum regulator current varies in various types. The maximum Zener current I_{ZM} is limited by the power dissipation of the diode. Between the limits of I_{ZK} and I_{ZM}, which are 5 ma and 1400 ma (1.4 amps) in the example of figure 5-23, the Zener voltage V_Z is essentially constant. The precise value of V_Z will change slightly due to temperature.

VOLTAGE REGULATION

Voltage regulation is required in many applications to correct for two kinds of circuit variables, which are (1) variations in input



25.86

Figure 5-22.—Zener diode current characteristics.

voltage level and (2) variations in circuit load. Load variations may be due to its normal operation during which the load voltage is to remain constant.

Figure 5-24 compares the Zener diode as a voltage regulator with the familiar gaseous tube regulator. The VR tube requires a supply voltage as much as 20 per cent higher than its regulated output voltage; the Zener diode breaks down, or conducts, at its specified voltage. Circuit operation of the two regulators is otherwise almost identical; however, the differences in physical and electrical characteristics point out the benefits of the Zener diode over the VR tube.

The gaseous regulator tube volt-ampere characteristics are established by the design and construction of the tube. The voltage level V_L is a function of the gas discharge characteristics established by the kind of gas used. As a consequence, the minimum voltage level which can be obtained is about 70 volts. The tubes are not ordinarily available over a small-change range of voltages, but vary in large jumps, such as 70, 90, 105, 135 volts, and so forth.

Zener diodes are not bound by voltage range limitations. They are available over a continuous voltage range in 5, 10, or 20 percent tolerance intervals from a minimum of 6.8 volts to a maximum of 200 volts.

In the VR tube, the constant voltage plateau is narrowly limited between two current quantities determined by the positions of the tube elements. Exceeding the maximum current limitation of the VR tube results in a higher voltage drop, a loss of regulation, and eventual destruction of the tube. In the Zener diode, the maximum current carrying capacity is limited only by the junction characteristics and the diode's ability to dissipate heat—considerations which make possible the production of Zener diodes over a wide range of power handling capabilities. In addition to the advantages of regulated output at almost any desired voltage level, Zener diodes have the added advantages of small physical size, extreme ruggedness, and extra filtering action.

ZENER SYMBOL

The Zener diode is normally used with reverse bias applied, and its operating

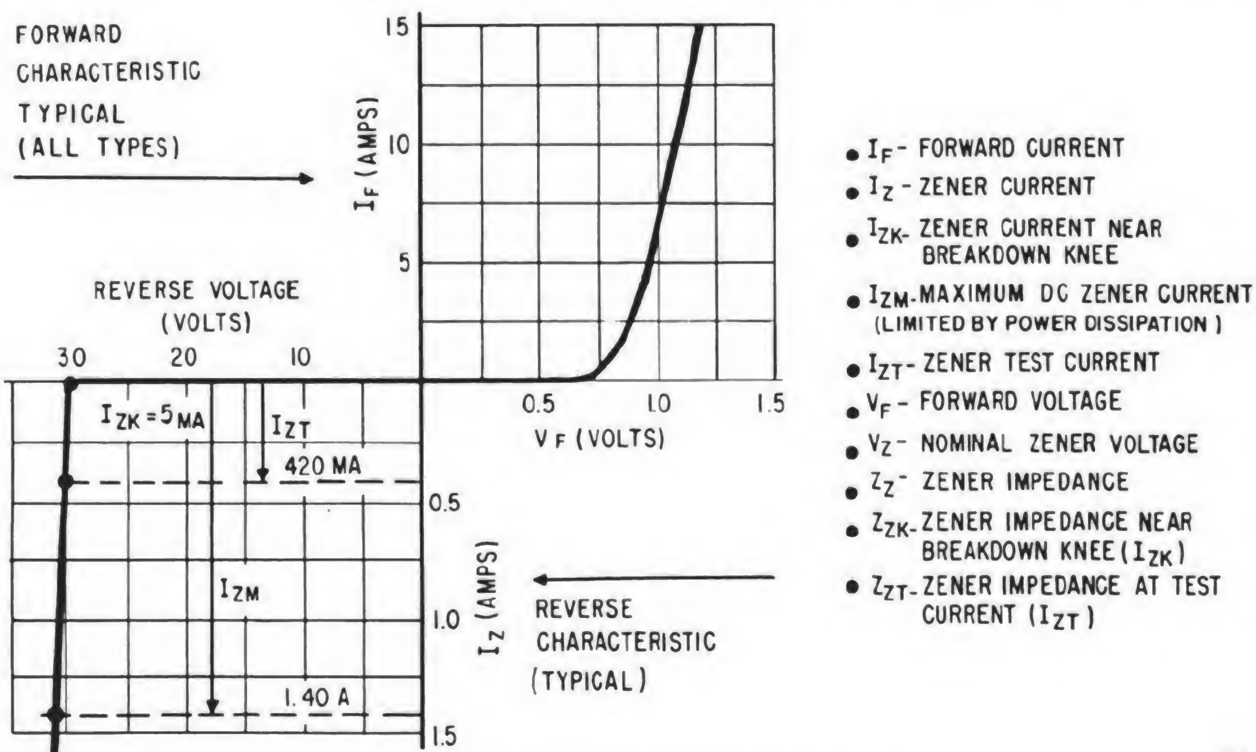


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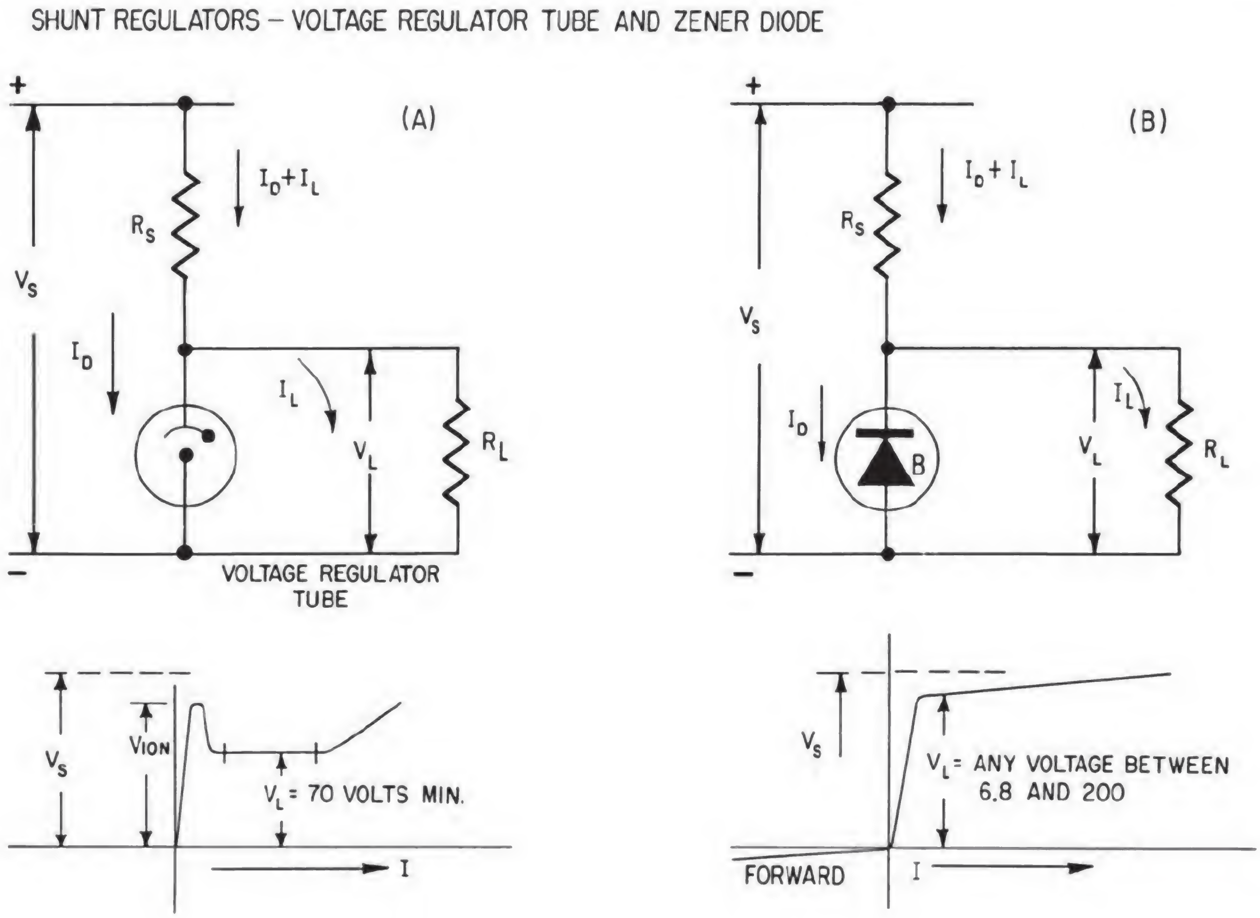
Figure 5-23.—Zener characteristic curve.



25.88

Figure 5-24.—Zener diode versus VR tube.

characteristics require that current flow be in the opposite direction from other solid-state diodes. Therefore, the symbol for the Zener diode indicates current flow with the arrow and is identified (in this chapter) by a small B beside the symbol (figure 5-24). The B indicates Zener or breakdown diode. No standard symbol has been established for the Zener diode as yet, but in schematics it will normally appear different in some respect from other diodes.

PRECAUTIONS IN SERVICING TRANSISTORS

Although the transistor is generally more rugged than the vacuum tube, the transistor is affected by electric shock, heat, nad humidity.

One of the most frequent causes of damage to semiconductor units is the electrostatic discharge from the human body when the unit is handled. Such damage may be avoided by discharging the body to the equipment before handling the unit.

A semiconductor unit may also be damaged by r-f fields. It is therefore essential that the unit be protected by a metal container until ready for use, at which time the equipment should be de-energized before the semiconductor is inserted.

When it becomes necessary to replace a transistor where the leads have been soldered, the following precautions should be taken. Before removing the old transistor, note the orientation of the collector, base, and emitter leads. Cut the leads of the new transistor to the proper

length, using sharp cutters to prevent undue stress on the leads entering the transistor. Then, with the transistor properly positioned, solder the leads to the connections, using the proper solder and soldering iron, and a heat sink. (For the proper method of soldering and other precautions in servicing transistors see chapter 6.)

For stability of the electrical characteristics the maintenance of the transistor hermetic seals cannot be over-emphasized. They not only maintain the carefully controlled environment in which the transistor is sealed; they also exclude moisture, which causes instability. While a transistor is warming up after exposure to low temperature, moisture may collect on the transistor surfaces, causing a large temporary increase in the collector current. With careful construction techniques, transistors are capable of operation in excess of 30,000 hours at maximum rating without appreciable degradation.

The minute power requirements of transistor circuits make it economically feasible to operate transistorized equipment with batteries, even where the equipment is subject to continuous use. Either conventional zinc-carbon batteries or the newer mercury batteries may be used. Battery eliminators should never be used as the source of power for transistors or any other semiconductor device. Because of the low current drain of transistor circuits, the voltage regulation of battery eliminators would be poor.

It should be remembered that temperature is the most important factor affecting transistor life, particularly the temperature of the transistor junction. The junction temperature is determined by the heat generated within, as well as the ambient temperature. For maximum transistor life, it is important to keep both the transistor and the ambient temperature as low as possible. It has been estimated that for every 10° C. the junction temperature is lowered, the life of the transistor is doubled.

It should be re-emphasized that care must be taken when servicing transistorized equipments that improper voltages are not placed across transistor leads. Proper bias voltages are also necessary, and if removed for only an instant, the transistor is likely to be damaged or destroyed. This means that the old practice of shorting points of a circuit to the chassis and listening for the "click" CAN NOT be used as a means of ascertaining the presence of voltage. One "click" and the transistor is gone. Beware of the use of "buzzers" for continuity checking in transistor circuits also. Such devices are likely to place excessive voltages across transistors in the circuit or to place a bias voltage in the wrong direction causing damage or destruction of the transistors.

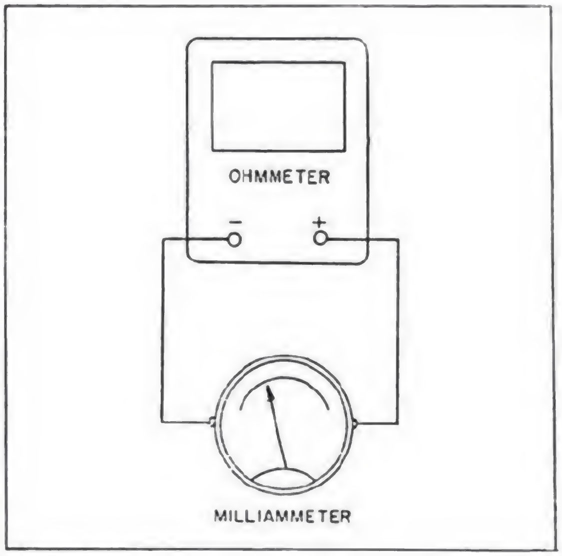
The techniques used in trouble-shooting transistorized circuits are not at all new to a technician with some experience in trouble-shooting any other type of circuit. However, certain precautions must be more carefully adhered to than before. One must be more careful when using test probes and test leads to avoid causing shorts, and one must be more careful in ensuring that proper voltages are used. On the other hand, the voltages used in transistor power supply circuits are generally much lower than those in tube circuits, so the danger of receiving a severe shock or painful burn from inadvertently touching an energized circuit is greatly reduced.

VOLTAGE AND RESISTANCE CHECKS

After a faulty section of the equipment is located, voltage and resistance measurements are made in a similar manner as on tube-type equipment. The same precautions for voltmeters and ohmmeters should be observed when testing transistorized equipment as when testing other equipments. In addition, it is important that the ohmmeter used does not cause excessive current to flow in the process of making resistance tests. Do not use an ohmmeter that passes more than one milliamp of current when short-circuited. A method of checking the ohmmeter is shown in figure 5-25. (NOTE: Some vacuum tube voltmeters also pass excessive currents, and should be tested in the same manner as described above for ohmmeters before they are used.)

TESTING AND REPLACING FAULTY TRANSISTORS

When trouble is isolated to a particular transistor that is believed to be faulty, remove the transistor from the circuit. If a transistor test set, TS-1100/U, is available, it is not necessary to remove the transistor from the circuit. This particular test set is designed



1.289
Figure 5-25.—Method of checking ohmmeter to ascertain that current will not exceed 1 milliampere.

to test the transistor while still in the circuit. However, it is necessary that the circuit supply voltage is turned off before making the test. Remember then, that the supply power is to be turned off—either if the transistor is to be tested in the circuit with the TS-1100/U, or if the transistor is to be removed from the circuit.

If the transistor is soldered into the circuit, observe the precautions concerned with soldering transistorized circuits as described in chapter 6 of this manual. After the transistor is removed, it may be checked in any transistor checker. If a transistor checker is not available, it may be checked for being leaky or shorted, or for being open, by making some simple resistance checks with an ohmmeter in the manner shown in figure 5-26. Be sure to observe the precaution noted earlier for making sure that the ohmmeter does not pass excessive current.

Before placing a transistor back into a circuit, make sure that there are no circuit shorts by making resistance checks at the appropriate terminals in the circuit with the transistor removed. Also make sure that the circuit supply power is not on at the time the transistor is placed in the circuit. Never pull and replace transistors in sockets while power is on. This may not cause harm in some tube circuits but is a practice that is strictly taboo when servicing transistors.

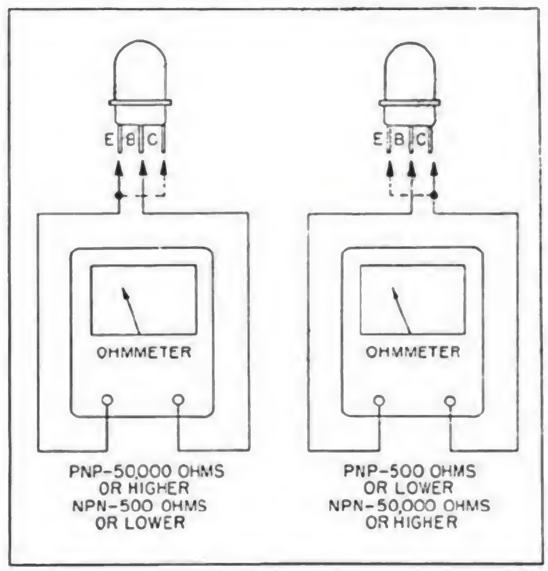


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Figure 5-26.—Transistor testing procedures.

CHAPTER 6

SUBMINIATURE REPAIR TECHNIQUES

TERMS AND DEFINITIONS

In this discussion of subminiature repair techniques, a number of technical terms are used. To help you understand the material, the following list of terms and definitions is provided.

ASSEMBLY—A number of parts (or subassemblies) or any combination joined together to perform a specific function.

MODULE—A unit or standard of measurement; a fixed dimension: a packaged functional assembly of wired electronic components for use with other such assemblies.

MODULAR ASSEMBLY—An assembly having outline dimensions which are multiples of a module.

UNITIZED CONSTRUCTION—A type of unitized-construction consisting, predominantly, of replacement assemblies.

MODULAR CONSTRUCTION—A type of unitized-construction consisting, predominantly, of modular assemblies.

EXAMPLES OF MODULAR CONSTRUCTION

A modular assembly may provide for either a single function or for multiple functions. Two or more modular assemblies may be used to form a portion of a unit which is replaceable as a whole, but which has a part or parts that are individually replaceable. These modular assemblies may be expanded to become building blocks in an ultimate tier. Analog computing systems which may be enlarged by the addition of package units containing amplifiers, function generators, potentiometers, and the like are an example of modular construction. The AN/FLR-11 Radio Set is also an example of modular construction. Two primary advantages of modular construction are the reduction of different replacement modular assemblies which must be maintained and the ease and rapidity of replacement. Modular construction provides for compactness with reliability which permits interchangeability. Examples A & B of figure 6-1 illustrate two possible configurations of modular construction.

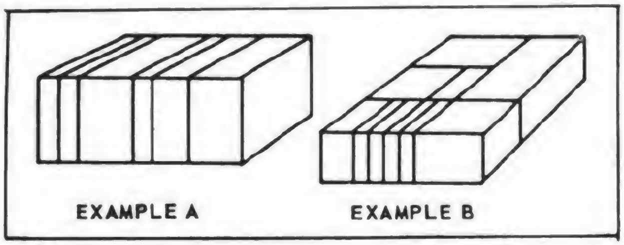
Certain standards must be met to successfully service modular assemblies. More skill is usually required for this kind of service than for the repairing of wired circuits. Specialized techniques, an adequate complement of tools, a certain degree of dexterity, and patience are musts for this type of servicing.

Subminiature construction features of modular assemblies, such as printed circuit boards, transistors, subminiature tubes, and pin assembly circuits (packaged units) make it necessary to use special repair techniques in most instances. These repair techniques will be discussed in the following paragraphs.

SPECIAL TOOLS AND SOLDER

The prime cause for part or board damage in modular-assembly repair is excessive heat and the use of improper tools and material. Special tools and material not ordinarily used in servicing the more conventional wired-circuit chassis are required. The main problem is the soldering iron. A light-duty soldering (pencil) iron (23-1/2 to 37-1/2 watts) should be used. A heavy-duty soldering iron should never be used.

A later discussion will explain in detail the techniques and specific procedures for soldering and removing parts. Personnel required to repair modular assemblies should be provided with at least one of the following recommended tools. Some of these tools are listed on the Electronic Tool Allowance List, and others, indicated by an asterisk (*), are procurable through local purchase. Figure 6-2 illustrates the commercial items.



70.120
Figure 6-1.—Modular construction.

All other tools used for repair of modular assemblies are standard hand tools and are listed in the electronics Tool Allowance List.

Selection of Proper Solder

Selection of the proper solder is the next step required for trouble-free repair. ALWAYS use a small-diameter, rosin-core solder with a tin-to-lead ratio of 60/40 (60 tin, 40 lead). NEVER USE A TIN-TO-LEAD RATIO OF 40/60. DO NOT USE a large-diameter solder with a high lead content. Use of this type of solder will result in damage to the printed circuit board, transistor, or other miniaturized part of the modular assembly, because of the excessive melting heat required.

High-quality solder of small diameter requires less heat to solder a strong and lasting joint. The ideal solder is known as EUTECTIC, a combination of 63 percent tin and 37 percent lead, which melts at 360° F. For all practical purposes the 60/40 solder, which melts at 370° F., can be used satisfactorily without damaging the modular components.

NOTE: An exception to this is in soldering a silver plated or solid silver circuit. For this application the solder must contain 2 percent to 3 percent silver, or a chemical reaction will set in, destroying the circuit.

CAUTION: Use only solder with a non-corrosive and non-conductive rosin core. Under no circumstances should an acid-core solder be used, because it will cause corrosion, shorts, and leakage.

PRECAUTIONS AGAINST MODULAR DAMAGE

Modular assemblies, although mechanically more rugged than conventional circuits, are comparatively easy to damage by improper handling or electrical overload.

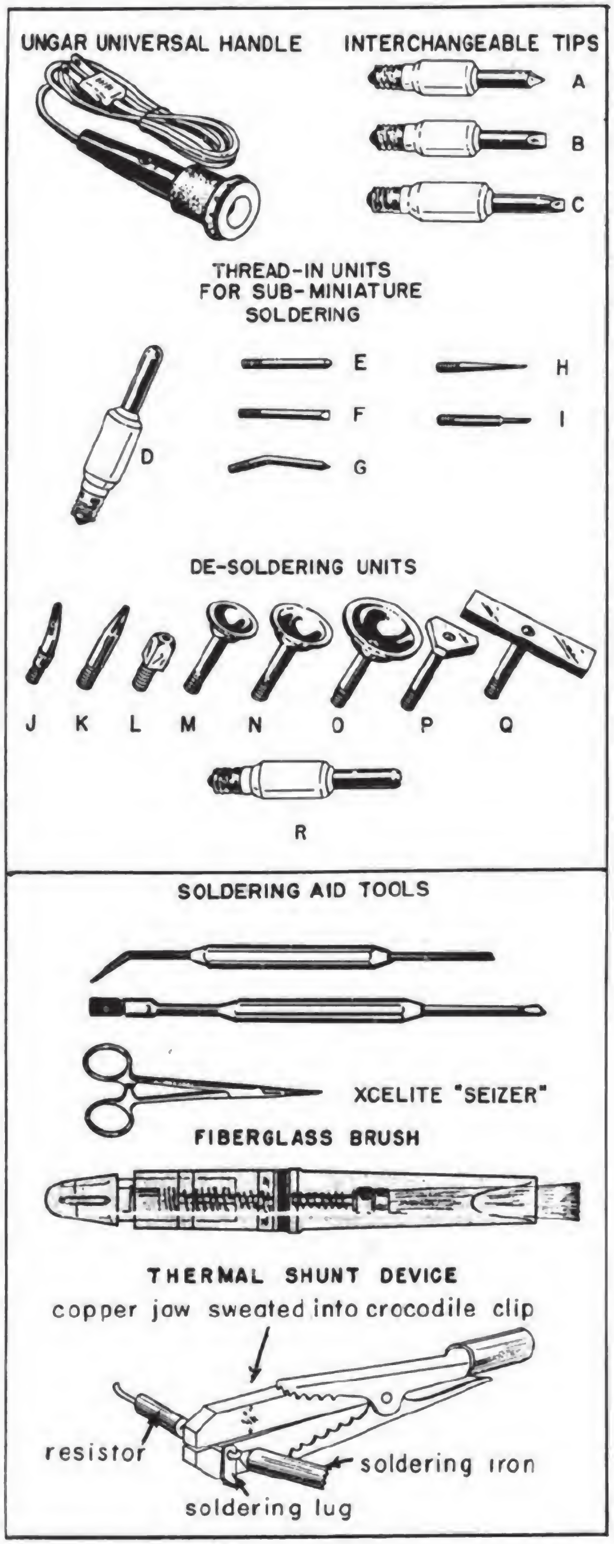
Considerable experience is required in working with transistors, printed circuits, or modular assemblies. It is necessary to keep certain general precautions in mind at all times. A number of these precautions are as follows:

DO NOT OVERHEAT transistors and other semiconductors, or any miniature parts. They can be destroyed by excessive heat. If it is necessary to solder or unsolder a semiconductor or other miniature part, use a clean, well-tinned pencil soldering iron and a good-quality, low-temperature solder. Complete the soldering process as quickly as possible. For maximum protection, hold the lead to be soldered with a pair of long-nose pliers or hemostatic clamp. The pliers or clamp should be held between the point where heat is applied and the body of the semiconductor or miniature part. Used in this manner, these tools form a "heat sink" to conduct heat away from the part itself. NOTE: Place a small piece of beeswax between the semiconductor and the hemostat. When it melts, the temperature limit has been reached. This is a warning to remove the source of heat immediately.

DO NOT EXCEED the absolute maximum electrical rating of the modular assembly under test or repair. These maximum electrical ratings are given in the technical manual tables and drawings supplied by the manufacturer for each part under test. Transistors, similar components, and associated miniature parts, are generally not underrated; consequently, there must be strict adherence to the maximum rating specified by the manufacturer and to the steps and procedures given in the technical manual.

OBSERVE POWER SUPPLY POLARITIES when measuring the resistance of the circuits of modular assemblies containing transistors, or other semiconductors. Such parts are polarity and voltage conscious. Reversing the plate-voltage polarity of a triode vacuum tube will keep the stage from operating, but generally will not injure the tube; however, reversing the collector-voltage polarity of a transistor, or another semiconductor, will ruin it, instantly and permanently.

Since transistors and similar components require different power-supply connections, the personnel who work with these parts must always be alert in connecting test equipment. Follow the directions given on the applicable tables or drawings to be sure that the correct polarity and range are observed. Recheck your work



70.121
Figure 6-2.—Recommended tools.

Item	Description	Federal or Commercial Stock No.
Soldering Iron—		
	*Ungar Electric Tools Co.	
	Pencil Iron Set	
	Handle assembly	776
	Thread-Units for Sub-miniature soldering	
A	Pyramid tip, 5/16" diameter	1236
B	Chisel tip, 3/8" diameter	1239
C	Chisel tip, 1/4" diameter	1233
D	Thread-in element for thread-in tips	1235
E	Thread-in straight cone tip, 3/8" diameter for element D	PL331
F	Thread-in straight chisel tip, 3/8" diameter for element D	PL332
G	Thread-in bent cone tip, 3/8" diameter for element D	PL333
H	Thread-in straight needle tip, 3/8" diameter for element D	PL338
I	Thread-in micro tip for element D	PL340
De-soldering Units for Sub-miniature Repair		
J	Thread-in offset slotted tiplet for element R	862
K	Thread-in straight slotted tiplet for element R	857
L	Thread-in hollow cube tiplet for element R	863
M	Thread-in 5/8" diameter cup tiplet for element R	856
N	Thread-in 3/4" diameter cup tiplet for element R	855
O	Thread-in 1" diameter cup tiplet for element R	854

Item	Description	Federal or Commercial Stock No.
P	Thread-in 5/8" diameter triangle tiplet for element R	861
Q	Thread-in 1-1/2" x 3/8" bar tiplet for element R	858
R	Thread-in element for de-soldering tiplets	4045
Soldering Aid Tools—		
	*General Cement Mfg. Co.	
	Soldering Aids .	
	Probe & alignment tool (with split & offset tips)	9093
	Scraper & brush tool	9094
	*Xcelite, Inc., Soldering Aids	
	Seizer (hemostatic) bent nose straight nose	42H
	Seizer (hemostatic	43H
	Soldering Aid Tool, 8-1/2" leg (with split & straight tips)	G5120-629-2697
	Forceps, surgical (hemostatic) straight nose, 5-inch leg	G6515-334-5600
	Forceps, surgical (hemostatic) bent nose, 5-inch leg	G6515-334-5600

before turning the power on—the wrong polarity will destroy the part.

GUARD AGAINST HIGH TRANSIENT CURRENT OR VOLTAGES when testing or servicing. A damaging transient pulse may be caused in a number of ways. The list that follows represents some of the most frequent accidental applications that should be prevented:

1. Application of a-c power operated test equipment or soldering iron without first making certain that no leakage current is emitted from them. The use of an isolation transformer is a good precaution to follow with all test equipment and soldering irons that are operated on a-c power, unless it has been determined that the equipment contains a transformer in its power supply or shows no current leakage. With all test equipment (whether transformer-operated or not), a common ground lead should always be connected first from the ground of the circuit to be tested, and then to the test equipment ground.

2. Application of too high a pulse from test equipment. The safest procedure is to start all test equipment from zero settings, and then proceed with the test steps as outlined in the manual for the equipment. Be sure that the signal applied is below the rating given for the circuit under test. Relatively high current transients can occur when test equipment is connected to a circuit where low-impedance paths exist.

3. Loosening connections, disconnecting parts, inserting or removing transistors or similar components, and changing modular units while the equipment power is on or while the circuit is under test. When changing modular assemblies, be sure that the equipment power is off. A loose connection or any of the actions mentioned will cause an inductive kickback. This can be prevented by being sure that all parts in the circuit are secure before starting the test or turning on the equipment power. Be sure to remove all possible capacitive charges from parts and test equipment before applying them to a modular assembly.

HANDLING AND PACKAGING

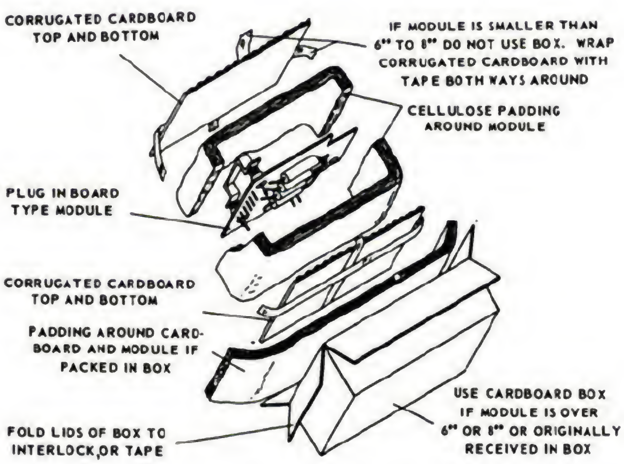
Handle modular assemblies carefully at all times. Unnecessary damage has occurred to modular assemblies by thoughtless, careless action in handling and packaging. Proper packaging of modular assemblies will prevent unnecessary damage. NOTE: Because a modular assembly is defective does not mean that it is beyond repair. Handle with care.

When a new module is received packaged in accordance with packaging specification, and the outer bulky casing (crate or outer carton with its shredded paper dunnage or similar material) is removed, the unit or units remain packed in a watertight package. This package is stored by the issuing activity until drawn by the using activity. Thus the using activity

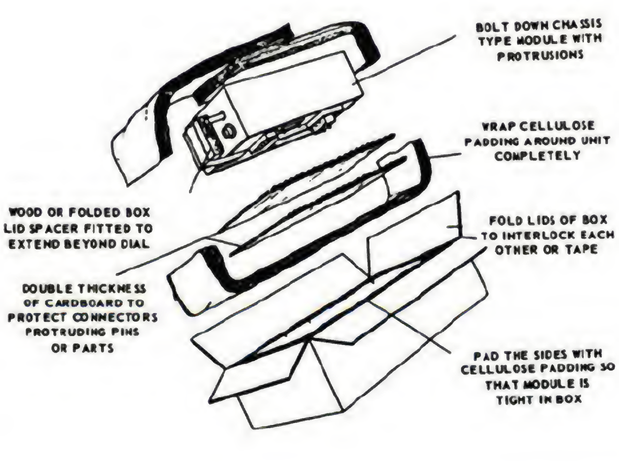
receives the necessary packaging material with which it can properly package a defective module.

For the correct method and the proper material to use for protective packaging of defective modules, see figures 6-3, 6-4, and 6-5.

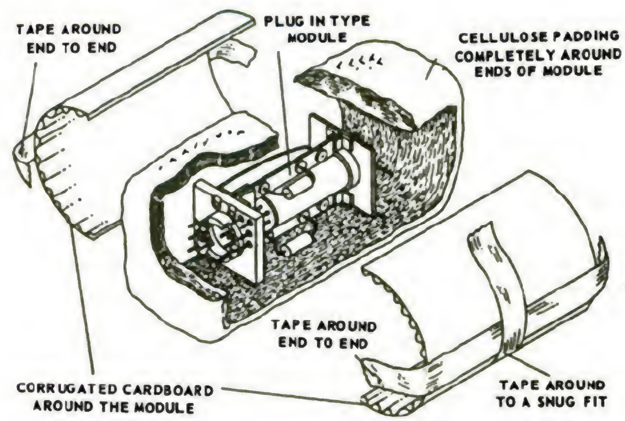
The material is available to all activities and should be used in the manner prescribed for



70.127
Figure 6-3.—Protective packaging of a bolt-down chassis-type module.



70.126
Figure 6-4.—Protective packaging of a plug-in board-type module.



70.128
Figure 6-5.—Protective packaging of a plug-in type module.

storing or transferring defective modules until they are received by a shipping facility, which will properly package them for shipment to the factory or restoration facility.

Regardless of the module design, if its pins, shafts, dials, or other protruding parts are adequately fitted with packing spacers and if the module is properly wrapped with protective cellulose (Kimpak or similar material), the using activity will have done its part in preventing transport damage to the modular assembly.

Desiccant crystals are normally packaged with assembled equipment crated for shipping. These crystals are retained in a bag and placed within the crated or packaged equipment in such a manner as to prevent them from jarring loose in the equipment. Do not use these desiccant crystals when packaging defective modules. Since the module must be packaged tightly, crystals in bag form cannot be used; the use of loose crystals may cause unnecessary damage, resulting in a cleaning problem.

If a modular assembly should become exposed to loose desiccant crystals, clean the assembly immediately. Do not turn its moving parts any more than absolutely necessary until assured that all of the crystal particles have been blown or brushed away. In testing the

moving parts for cleanliness, turn them very slowly and gently—Do not force if gritty. Work out the crystal particles with a brush or compressed air. Wash the modular assembly in an approved solvent (P-S-661a Dry Cleaning Solvent, Type II, Stock No. W6850-274-5421), brush and blow dry, then check and test the assembly (as instructed in the equipment manual) before using it in the equipment. If the equipment functions improperly, check the assembly for the presence of crystal particles. Before replacing the assembly, repeat the cleaning procedure. If the equipment remains defective, replace it. Unnecessary damage has occurred to modular assemblies because of rough handling. Particular care must be given to the method of removing or inserting a module into the equipment. If the module is a plug-in, board-type assembly, be sure the guide pins are properly alined before pressing the assembly in place. If the board should tilt while being inserted, do not continue to press it into position; straighten it, then apply even pressure to avoid tilting. Forcing any tilted or cocked modular assembly into position may result in bent or broken pins.

When removing a modular assembly, be sure to pull it straight out from the equipment. Because of the miniaturization of parts for modular construction, leads, connectors, pins, etc., have been stiffened to make them more rugged. As a result, such fragile parts are brittle and will break easily if bent too often or when uneven pressure is applied. When handling a module that has been removed from its chassis, be careful not to press against the leads and pins. If a lead or pin is accidentally bent, do not try to straighten it unless absolutely necessary.

When repairing a modular assembly, be careful that the tool employed does not inadvertently press against leads, pins, or other parts that are easily bent. Such pressure can destroy a good part and cause needless repair.

REMOVAL AND REPLACEMENT OF PARTS

Replacement of miniature and subminiature parts found in modular assemblies requires more consideration than is normally given to parts in the servicing of other electronic equipment. Before attempting repair, maintenance personnel should become thoroughly familiar with the correct repair and soldering techniques, since servicing procedures used differ in a number of ways.

EMERGENCY SOLDERING IRON

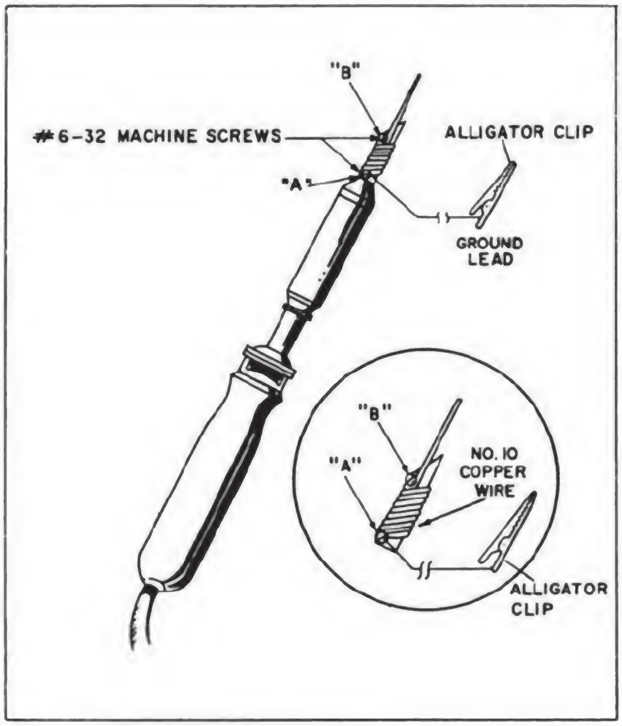
The compactness of modular assemblies makes it imperative that a small, low-wattage pencil iron be used. The soldering iron should have a small tip so that heat can be applied directly to the terminal of the part to be removed or replaced, without overheating the printed board or adjacent parts. The recommended Ungar pencil iron set, described earlier, is designed for this type of work. If a low-wattage iron is not available, a high-wattage iron can be effective when converted to a low-heat unit for emergency use only. To make the conversion, closely wrap any number of turns of clean No. 10 copper wire around a thoroughly clean soldering iron tip, extending the other end of this wire 1 inch beyond the original soldering iron tip. Thoroughly tin the formed end of the new tip before using. This then will serve as a low-wattage soldering iron tin (figure 6-6).

To provide a tight connection and prevent possible twisting of the tip, the No. 10 wire coil end should be secured at points "A" and "B" with No. 6-32 machine screws. The foregoing instructions apply to all subsequent examples of improvised soldering tips.

A flexible ground wire (No. 14) should be attached to point "A", figure 6-6. The other end of this wire should be provided with an alligator clip to permit convenient grounding of the soldering iron to the module chassis. CAUTION: If an improvised high-wattage soldering iron is to be used for work on transistors or other transient voltage sensitive components, a ground lead must be connected from the tip of the soldering iron to the frame or chassis of the module. This is necessary to prevent damage to transistors and other parts due to leakage current in the soldering iron.

CHASSIS-HOLDING JIG

It is recommended that a chassis-holding jig—with sufficient versatility to accommodate



70.123A
Figure 6-6.—Improvised soldering tip for modular repair.

most types of modular assemblies—be constructed as illustrated in figure 6-7. This jig will provide support for the modular assembly when removed from its regular mounting for repair. It will also prevent flexing or slipping, which could result in unnecessary damage.

This jig is constructed of 1-inch by 4-inch milled lumber of which only 2 feet 3 inches are required if cut to the dimensions given. Three round-head slotted machine screws (10-32-1 3/4 inch long), three flat washers (.199 ID-3/8 inch OD—.064 inch TK), and three common hexagon nuts (No. 10-32) are the required hardware. The fixed head and feet are dowel fitted and glued as shown in figure 6-7. The illustrated jig will hold a modular assembly up to approximately 10 inches wide. The jig should be secured to the work area by "C" clamps or held in a vise.

DESOLDERING SET

A practical soldering iron, with tips specially designed for soldering and unsoldering parts from printed circuit boards, has been developed by Ungar Electric Tools, Inc.

The Ungar off-set or straight slotted tiplets (Ungar No. 862 & 857) will simultaneously melt the solder and straighten the leads, tabs, and small wires bent against the board or terminal, as illustrated in figure 6-8A. If this tool is not available, the improvised soldering tip shown in figure 6-6 may be used with a split-end soldering aid tool (General Cement Mfg. Co. No. 9093), or pocket penknife as illustrated in figure 6-8B.

The Ungar bar-type tiplet (Ungar No. 858) will remove straight-line multi-terminal parts quickly and efficiently, as illustrated in figure 6-9A. The removal of this type of part may be accomplished by individually heating each solder connection and brushing away the melted solder with a wire brush, as shown in figure 6-9B. In using this method, particular care must be taken to prevent loose solder from making contact with other parts or to the printed panel, where it may cause a possible short.

Another method involves the use of a piece of No. 10 copper wire. One end is wrapped around the soldering iron tip and the other end of the wire is fashioned to cover all of the lug connections simultaneously, as illustrated in figure 6-9C. Care must be exercised to ensure physical contact with the terminals to be unsoldered and nothing else. Do not allow the tool to remain in contact with connection for prolonged periods of time. Remove the tool after a short time, wipe off the excess solder, and then reapply. This permits the area to cool, thus protecting the printed board and parts from being burned or destroyed by concentrated heat.

The Ungar cup-shaped tiplets (Ungar No. 854, 855, and 856), the triangle tiplet (Ungar No. 861), and the hollow-cube tiplet (Ungar No. 863) are specially designed to withdraw solder from circular or triangular mounted parts in one operation, as illustrated in figure 6-10A. If these tools are not available, an improvised soldering tip can be used for circular or triangular mounted parts in the same manner as

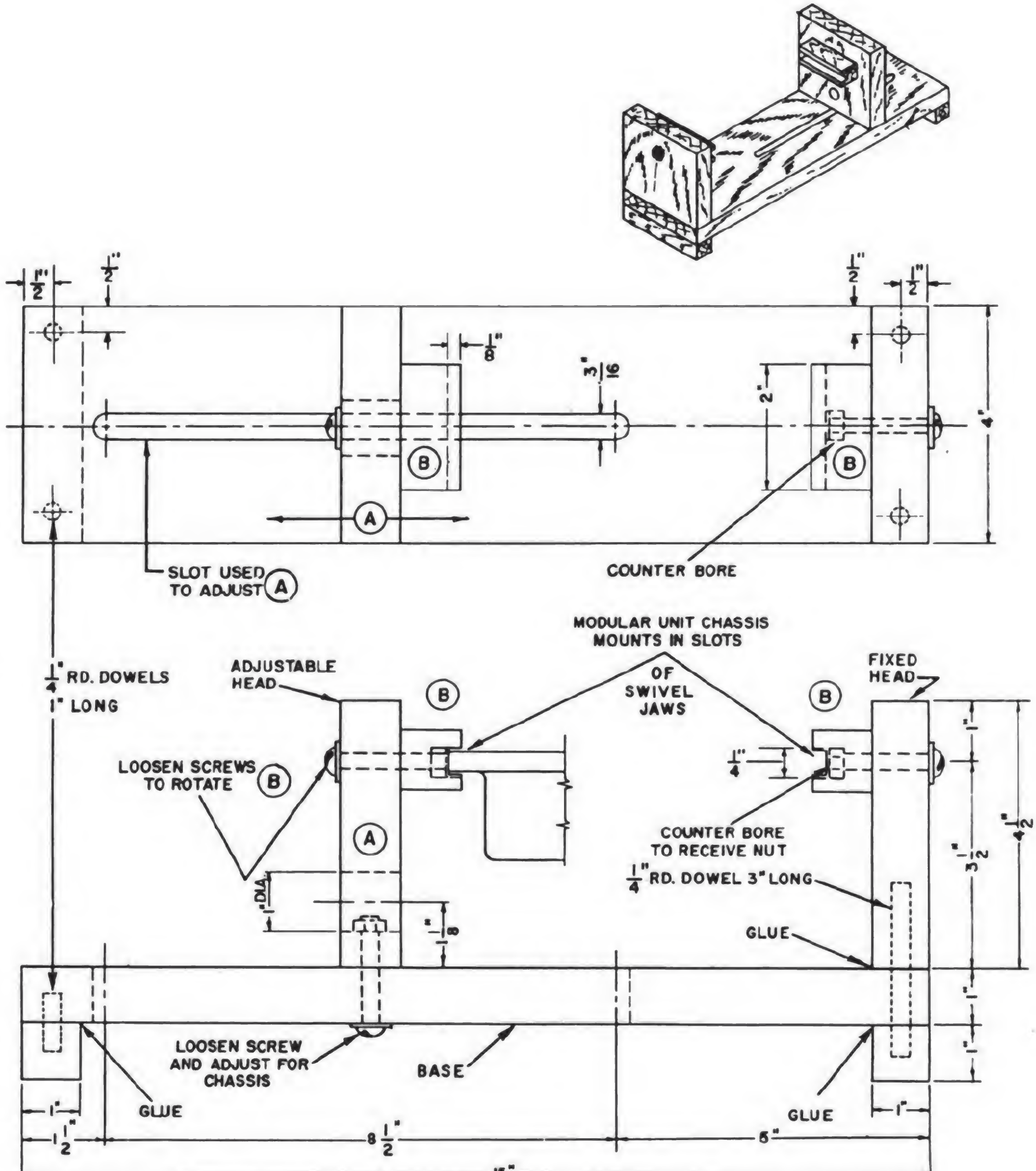


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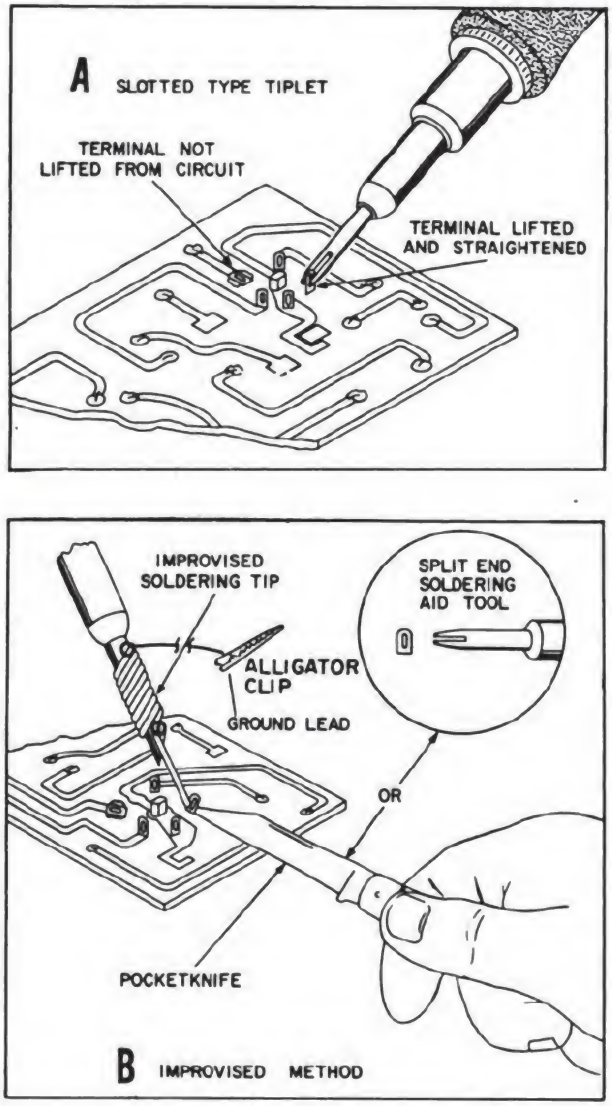
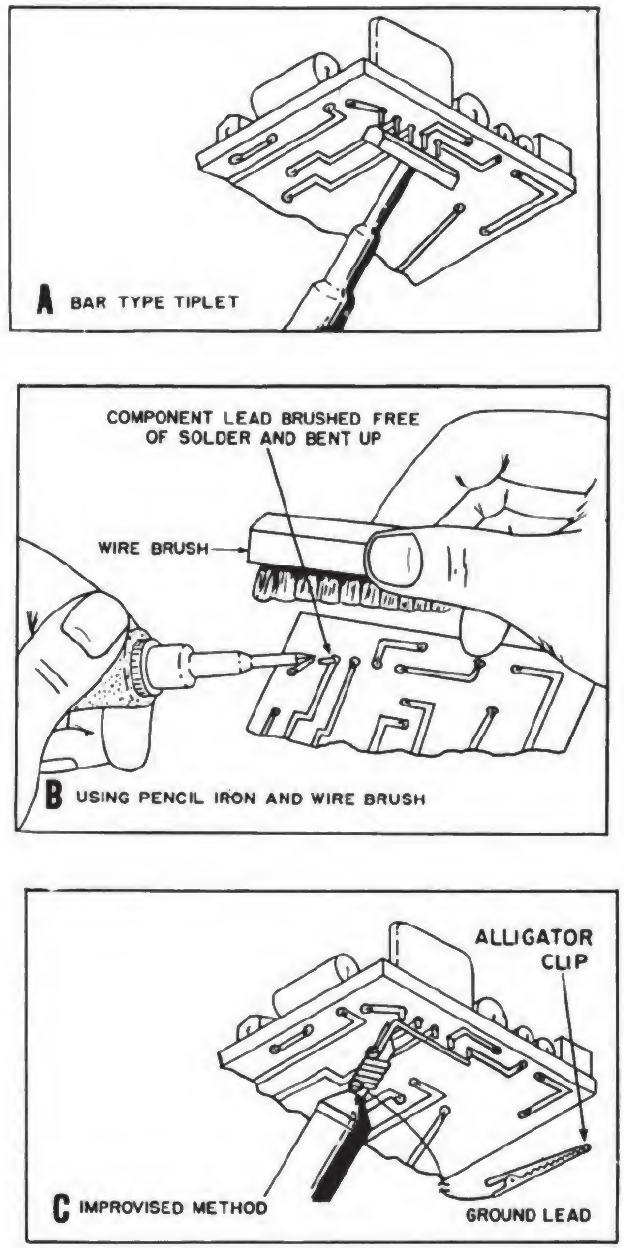
Figure 6-7.—Chassis holding jig.

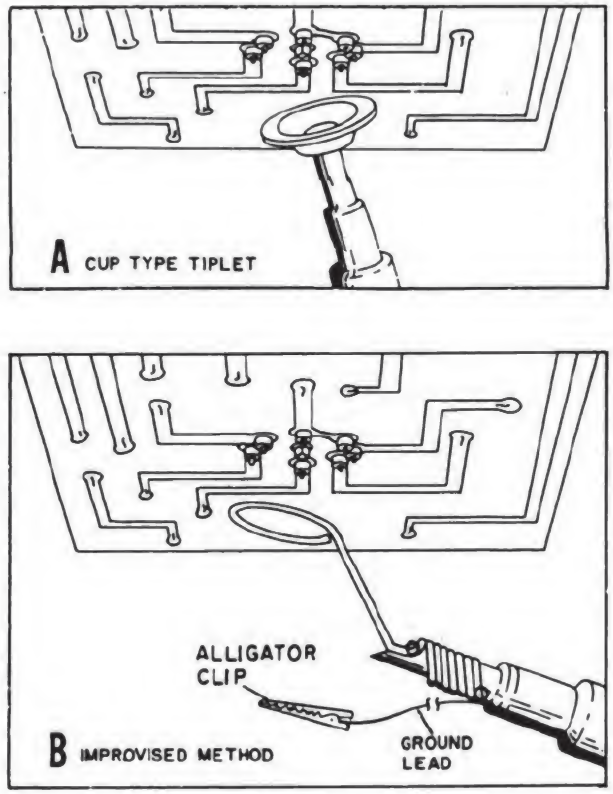


70.124
Figure 6-8.—Special soldering iron adaptations.

described previously for the improvised tip for straight-line multi-terminals. This method of removing circular or triangular mounted components requires the use of No. 10 copper wire with one end wrapped around a soldering iron tip, the other end of the wire shaped to cover all of the lug connections simultaneously, as illustrated in figure 6-10B. This tool must be applied with care to the terminals of the part to be removed, so as not to touch the printed circuit board or its associated parts. Prolonged application of this tool will develop a concentration of heat which can damage the printed circuit board or its associated parts. It is better to apply the tool for a short time, remove and wipe off the tool, then reapply,



70.124
Figure 6-9.—Special soldering iron adaptations.

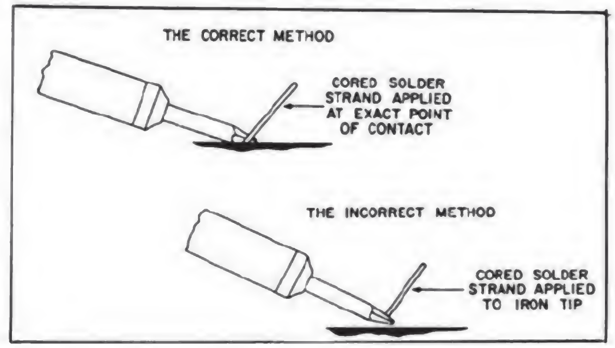


70.124
Figure 6-10.—Special soldering iron applications.

rather than try to remove the solder from all of the connections in one concentrated application.

The most important technique required in the repair of modular assemblies is skill in the soldering and unsoldering of the parts. Careless work creates unnecessary damage. Take time and be precise.

In the application of solder, remember that the iron must heat the metal to solder-melting temperature before actual soldering can take place. The flat side of the soldering-iron tip should be held directly against the parts to be soldered. The solder-melting temperature is reached in a matter of seconds (5 to 10 seconds), therefore, the soldering iron and the solder strand must be applied simultaneously. Apply the solder to the point of soldering-iron contact—not to the soldering iron. Figure 6-11 illustrates both the correct and incorrect manner of the solder application.



70.123
Figure 6-11.—The correct and incorrect methods of solder application.

Be sure the terminal, lead, or any portion of a part to be soldered has been properly cleaned and tinned before positioning it for soldering. Do not tin printed circuit terminals; just clean moisture, grease, or wax from the printed ribbon with a stiff-bristle brush and Methyl Chloroform (GM6810-664-0387) or alcohol. (See Handbook of Cleaning Practices, NavShips 250-342-1.)

Be sure cleaning solvent is dry before applying the hot soldering iron. Alcohol is flammable. Methyl chloroform is not highly flammable, but heating it increases its toxic hazard. Although the vapors of methyl chloroform are much less toxic than carbon tetrachloride, they are still harmful. Use methyl chloroform only with adequate ventilation. Avoid prolonged or repeated breathing of vapor or contact with skin. Do not take internally.

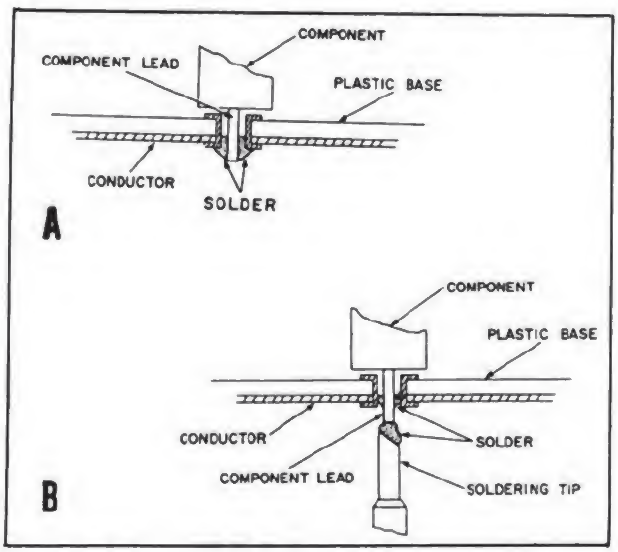
Removal of a part without damaging the printed circuit board and its associated parts requires that the soldering tool be used with precision and skill. Thought should be given to the most appropriate procedure to use in the replacement of the part involved.

DEFECTIVE-PART REMOVAL PROCEDURES

The following procedures are typical and should be applied in any combination applicable:

To remove a defective part, position the modular assembly in a jig (figure 6-7) or similar device, so that the terminals to be unsoldered are facing out and down, as shown in figure 6-12A. Place the tip of a hot soldering pencil iron under and against the terminal, as shown in figure 6-12B, drawing off the solder. The solder will flow to the soldering iron tip and is then removed from the tip by wiping it on a cloth. Remove all the solder that can possibly be removed from each of the terminals. When the terminals have all been loosened, lift the part from the printed wiring board.

The part to be removed should not be pried or forced loose. Any attempt to force a part loose may result in a broken printed-circuit panel. If the terminals do not pass easily through their holes, all of the solder has not been removed.



70.123
Figure 6-12.—Correct method for removing solder from component without damaging the printed wiring circuit.

If the solder remains in the terminal hole after removing the leads, apply the soldering iron to the terminal hole just long enough to soften the solder. Clear the hole by inserting a toothpick or similar implement to remove the softened solder.

INSTALLING A NEW PART

Before installing a new part, clean the area from which the old part was removed of any moisture, grease, or wax, using a short, firm-bristle brush and approved solvent (Methyl Chloroform GM-6810-644-0387). Be sure cleaning solvent is dry before applying soldering iron. Before installing the new part, preform and tin its leads correctly, so that the part will slip easily into position on the board, without placing strain on the printed-board terminals.

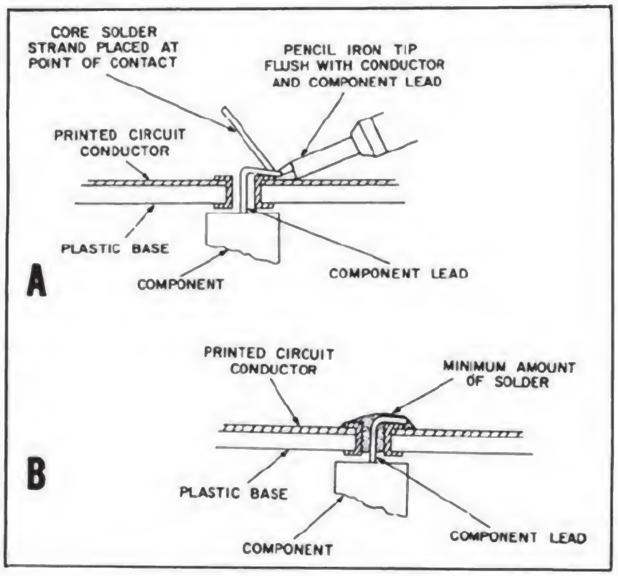
Position the new part firmly, then, with diagonal cutting pliers, trim the leads to approximately 1/8 inch from board terminal. Bend each trimmed lead over and against the printed circuit conductor, as shown in figure 6-13A. Solder the leads to the printed-circuit-board terminal, using a minimum amount of solder as shown in figure 6-13B, being careful not to overheat the printed board. This method assures a good contact with the printed circuit, and results in a rigid mounting which will not allow the printed conductor to separate from the terminal.

PRINTED CIRCUIT PART AND ASSEMBLY REPLACEMENT

It is always desirable to replace parts on a printed circuit board without applying heat directly to the conducting strip. This procedure prevents damage to the printed circuit conductors, feed-through devices, eyelets, or terminals and saves time in repair. It also prevents damage to semiconductors and other heat-sensitive parts that may be in proximity to the part being repaired.

Replacing parts requires that each type of part mounting be considered individually for the best method of removal.

A part to be removed may be too close to a heat-sensitive semiconductor or other part to



70.123
Figure 6-13.—Correct method for applying solder to a replaced component.

allow the hot pencil-soldering iron to be applied. A quick test to determine this safe distance is to place your finger between the semiconductor (or heat-sensitive part) and the part to be removed. If the heat is too great for your finger when the soldering iron is placed by the defective part, it is also too hot for the neighboring component. If determined that the heat-sensitive part is too close, place a shield (asbestos or like substance) between the parts before applying the hot soldering iron, and place heat sink clamps on all leads from the heat-sensitive part.

Solid-state parts and their associated circuitry are extremely sensitive to thermal changes. Therefore, particular care must be taken to prevent exposing them to heat. Heat sinks and shunts must be applied with shields inserted to protect the associated parts any time repair or removal of a part requires the use of a hot soldering iron. Solid-state parts and associated assemblies require the same care in handling and skill of repairing that is applied to assemblies in equipment of unitized or modular construction containing transistors, tantalum capacitors, crystals, and similar components.

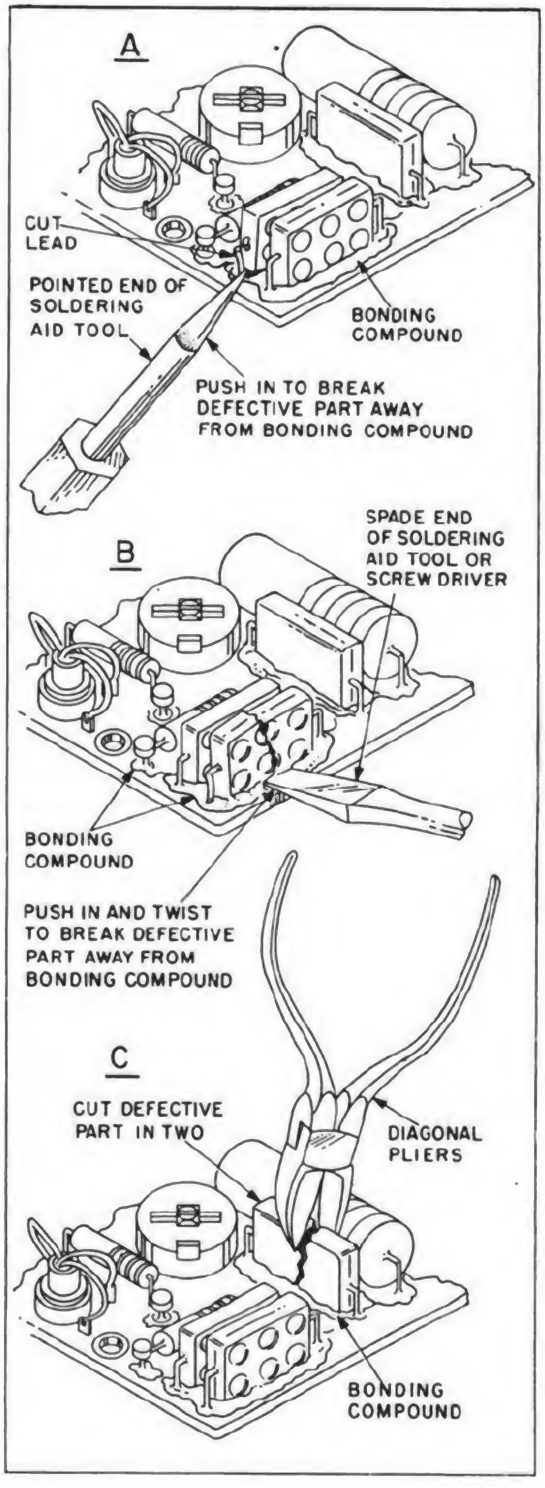
AXIAL-LEAD REPLACEMENT

Removal of an axial-lead part that has been bonded to a printed circuit board (with an epoxy resin or similar compound) can be accomplished by breaking the defective part or by applying heat to the bonding compound. The method to be used depends upon the part itself and its location.

If the defective axial-lead part cannot be removed by heat, cut or break the part away from the bonding compound, as shown in figure 6-14. Figure 6-14A and 6-14B illustrate two different methods of breaking the part away from the bonding compound where the part is too close to other parts to use cutting pliers. Wherever possible, cutting the defective part with end-cutting pliers or diagonals, as shown in figure 6-14C, is the preferred method to use.

Regardless of which tool is employed (round-pointed or spade type), great care must be used in its application to prevent the printed circuit board or other parts from being damaged or broken. Apply the point of the tool against the bonding compound, between the part and the printed circuit board. Use the tool in such a manner that it works away the bonding compound from the part to be broken away until enough has been removed for the tool to exert pressure against the part. Keep the leverage surface area of the tool flat against the surface of the printed circuit board; this helps to prevent the tool from gouging or breaking the board. Be careful—never apply excessive pressure against a printed-circuit board.

After the defective part has been removed from the bonding compound, remove the leads or tabs from their terminals on the printed circuit board. Clean the area thoroughly before installing the new part. However, do not remove the bonding compound left under the removed part unless its condition requires it. The mold left in the compound should be the same as the new part; thus, inserting the new part in this mold helps to secure it from vibration. After the repairs have been completed and the circuit tested, spray the newly soldered area with an insulating varnish (MIL-V-1137A



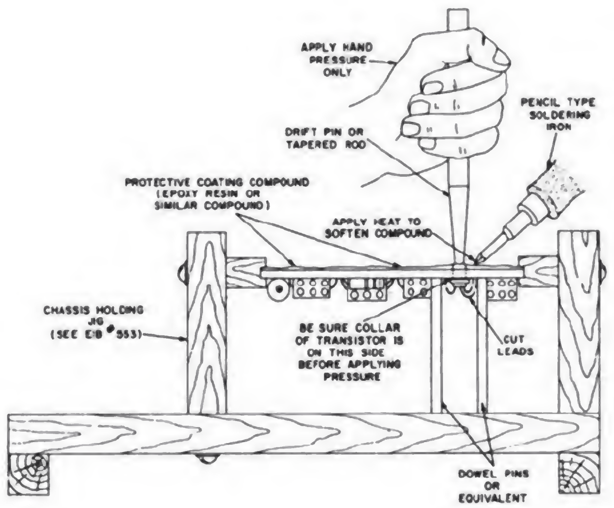
70.113
Figure 6-14.—Removing a defective part from bonding component.

or equivalent). Coat the new part or parts with a bonding compound ("Eccobond-55" by Emerson & Cuming, Inc., Canton, Mass.; "Relix-R-313" by Carl H. Briggs Co., W. Los Angeles, Calif. or equivalent). A later discussion will explain bonding techniques in detail.

TRANSISTOR REPLACEMENT

To replace a proven defective transistor, first cut all of its leads, and then remove it from the assembly. Transistors are mounted on circuit boards in many different ways; thus it is necessary to study how a particular transistor is secured before attempting to remove it. A transistor with clamp-type mounting requires only a pointed tool between the clamp and the transistor to remove it. A transistor mounted in a socket may have a wire or spring clamp around it. Remove this clamp before pulling the transistor out of the socket. In some instances the transistor is bolted through the board. Remove the nut and washer, and then remove the transistor. Where vibration is a prime factor, the manufacturer mounts the transistor through the circuit board and bonds it (with epoxy resin or similar compound.) For this type, a flat-ended round-rod-type tool (drift punch) of a diameter less than that of the transistor case is required. Place the printed circuit board on which the transistor is mounted in a chassis holding jig, in such a way that pressure exerted against the board will be relieved by proper support on the other side, as shown in figure 6-15. Apply a hot-pencil soldering iron to the bonding compound and simultaneously apply the drift punch against the top of the transistor, exerting enough pressure to force the transistor from the softened compound, and on through the board, as indicated in figure 6-15.

Before installing the new transistor, great care must be taken to prepare the part for installation. Test the transistor in a transistor tester (TS-1100/U or similar test equipment) before installing. This precaution will assure that the transistor is good before it is installed. Preshape and cut the new transistor leads to the shape and length required for easy replacement. Use sharp cutters, and do not place undue stress on any lead entering the transistor. The leads are fragile, and are therefore susceptible to breaking by excessive bending or too sharp a bend. Shape any bend required in a gradual curve, and at least



70.114
Figure 6-15.—Removing a transistor that has been through-board mounted.

1/4 inch to 3/8 inch from the base of the transistor. A safety measure which can be taken to ensure that the lead will not break off at the base is to use two pairs of needle-nose pliers. With one pair grasp the lead close to the transistor base, while shaping the rest of the lead with the other pair.

The above procedure and precaution should be applied to any and all semiconductors, tantalum capacitors, and other miniaturized parts in equipment of modular or unitized construction.

After the remaining pieces of the defective transistor-terminal leads have been removed and the terminals on the board cleaned and prepared, connect the new transistor to its proper terminals. REMEMBER: Handle any semiconductor or miniaturized part carefully; be gentle and be precise.

Where the defective transistor was removed from a through-board mounting and bonded, care must be taken that the new transistor clears the hole before it is connected to its terminals. If the hole is too large, shim with a thin plastic sleeve (fabricated). If the hole is too small, ream it to accept the new transistor. Rebond the fitted transistor after testing the repaired circuit and it is proven to be operative. Do not use heat to rebond replaced semiconductors.

MULTI-LUG PART REPLACEMENT

To remove and replace a multi-lug part, such as a transformer, choke, filter, or other similar potted, canned, or molded part, release the part from its mounting before disconnecting or cutting its conductors. Before applying pressure to remove such a part, carefully inspect it to be sure that the part is completely free of all its connections to the printed circuit board, and that all bent or twisted mounting lugs have been straightened; otherwise, you may break the board by applying undue pressure.

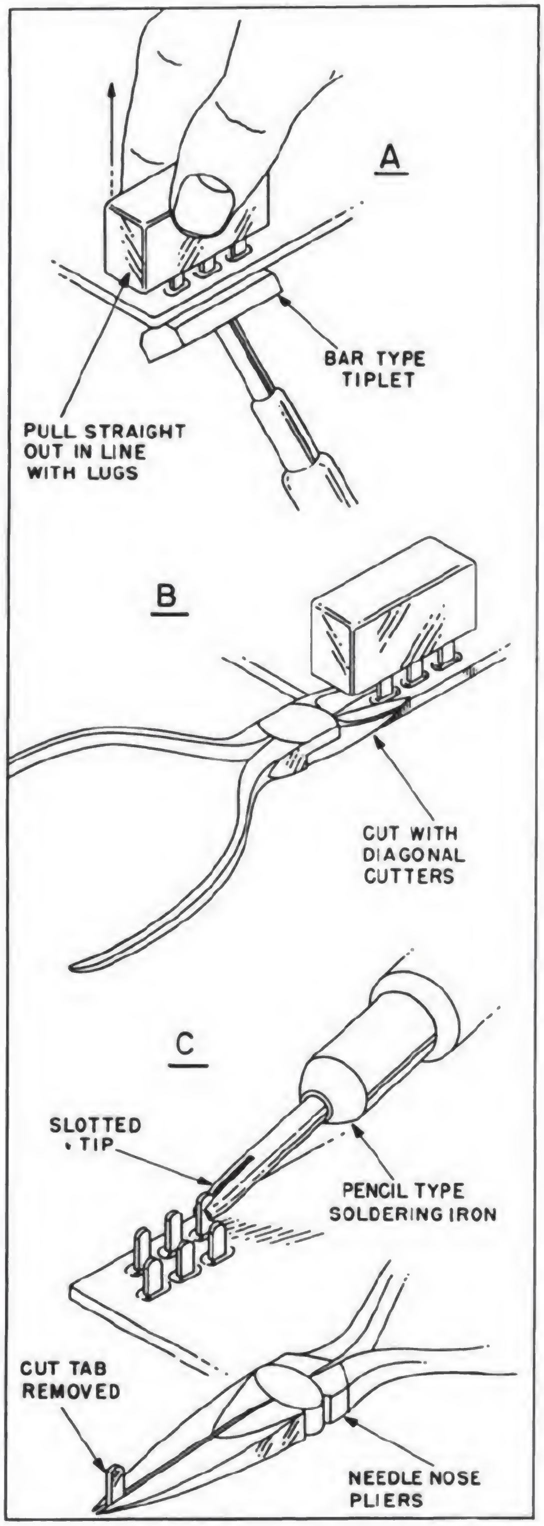
Never wrench or twist a multi-lug part to free it, because this will cause the conducting strip to become unbound from the board. Work this type of part in and out in line with its lugs, as shown in figure 6-16A, while applying a hot-pencil soldering iron (using a bar-type tiplet adapter or similar desoldering tool).

Wherever possible, cut the conducting or mounting leads and lugs of the defective multi-lug part on the mounting side of the board, as shown in figure 6-16B. Heat and straighten the clipped leads with a hot-pencil soldering iron and slotted soldering-aid tool (or slotted soldering-iron tiplet adapter or similar desoldering tool) applied to the circuit side of the board; pull the leads or tabs through with pliers, as shown in figure 6-16C.

To replace the new multi-lug part, be sure that all of the lead holes or slots are free and clean, allowing easy insertion of the multi-lug part. DO NOT FORCE ANY PART INTO POSITION ON A PRINTED CIRCUIT BOARD—YOU MAY BREAK THE BOARD OR LIFT THE PRINTED CIRCUIT CONDUCTIVE STRIP AND EYELET TERMINAL. If the part does not position easily, check and rework the terminals and holes (or slots) until it seats freely; then solder.

Be very careful when replacing defective parts that have leads terminating on stand-offs, or feed through terminals. Usually they are very small and are mounted on a thin phenolic board which makes them susceptible to damage by heat and undue pressure.

ALWAYS REMEMBER—WHEN SERVICING ANY ELECTRONIC ASSEMBLY—HANDLE WITH CARE—BE PRECISE—AND BEWARE OF USING EXCESSIVE HEAT OR FORCE.



70.115

Figure 6-16.—Removing a defective multi-lug part.

TROUBLE SHOOTING AND REPAIR OF PRINTED CIRCUITS

Although the trouble-shooting procedures for printed circuits are similar to those for conventional circuits, the repair of printed circuits requires considerably more skill and patience. The printed circuits are small and compact; thus personnel should become familiar with the special servicing techniques required.

PRELIMINARY PROCEDURES

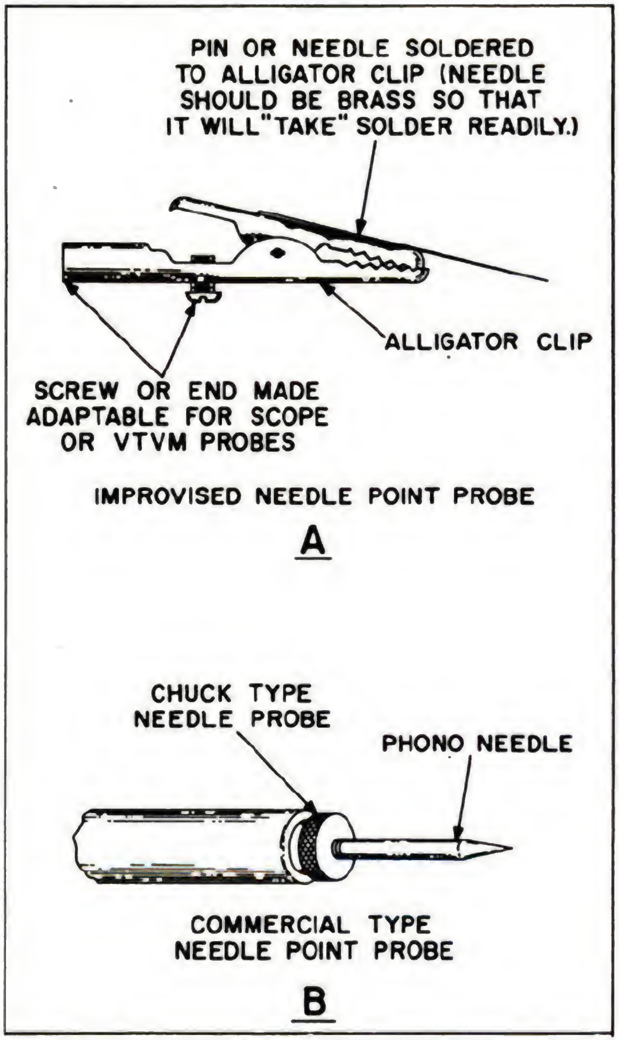
In all instances, it is advisable to first check the defective printed circuit before beginning work on it to determine whether any prior servicing has been performed. Not all personnel having access to this type of equipment have the skill and dexterity required; hence, some preliminary service may be necessary. By observing this precaution you may save a great deal of time and labor.

The defective part should be pin-pointed by a study of the symptoms and by careful and patient analysis of the circuit before attempting to trace trouble on a printed-circuit board. Ascertain whether the conducting strips are coated with a protective lacquer, epoxy resin, or similar substance. If so, carefully scrape it away, or, better still, use a needle or chuck-type needle probe, as shown in figure 6-17, which will easily penetrate the coating for continuity check.

Breaks in the conducting strip (foil) can cause permanent or intermittent trouble. In many instances, these breaks will be so small that they cannot be detected by the naked eye. Hairline cracks (breaks) can be located only with the aid of powerful hand- or stand-held magnifying glass, such as No. HH6650-252-6250 (hand-held type), or Bausch & Lomb Optical Co. P/N 81-34-66 with horseshoe-type stand, as illustrated in figure 6-18.

Point-to-Point Resistance Tests

To check-out and locate trouble in the conducting strips of a printed-circuit board, set up a multi-meter (one which DOES NOT pass a current in excess of one milliampere) for making point-to-point resistance tests, as shown in figure 6-19. Use needlepoint probes and insert one point into the conducting strip, close to the end or terminal, and place the other probe on the terminal or opposite end



70.109
Figure 6-17.—Needle probes.

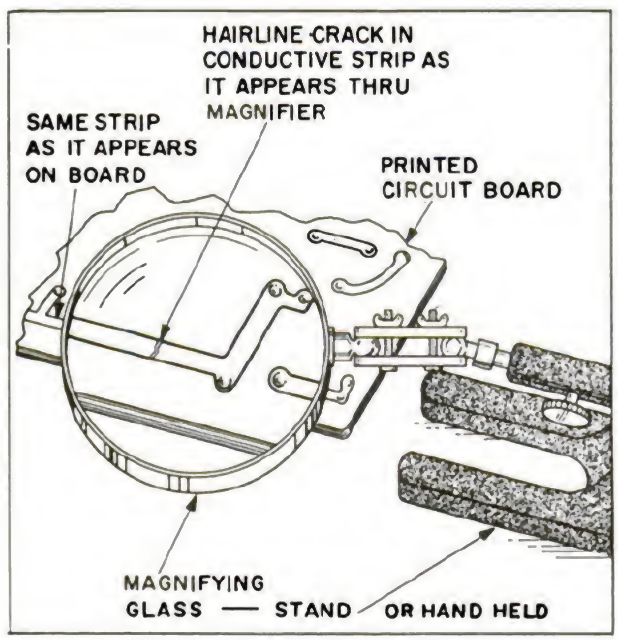
of the conducting strip. The multimeter should indicate continuity. If the multimeter indicates an open circuit, drag the probe along the strip (or if the conducting strip is coated, puncture the coating at intervals) until the multimeter indicates continuity. Mark this area and then use a magnifying glass to locate the fault in the conductor. CAUTION: Before using an ohmmeter for testing a circuit containing transistors or other voltage-sensitive semiconductors, check the current it passes under test on all ranges. DO NOT use a range that passes more than one milliampere.

REPAIRING DAMAGED STRIPS

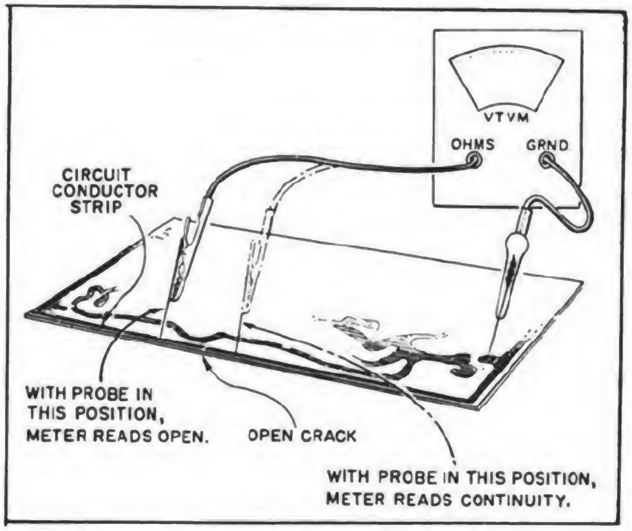
If the break in the conducting strip is small, lightly scrape away any coating covering the area of the conducting strip to be repaired. Clean the area with a firm bristle brush and approved solvent, then repair the cracked or broken area of the conducting strip by flowing solder over the break, as shown in figure 6-20A. If there is any indication that the strip might peel, bridge the break with a small section of bare wire (approximately 2 inches) by the method shown in figure 6-20B. Apply solder along the entire length of the wire to bond it solidly to the conducting strip. Considerable care must be exercised in applying the solder to prevent it from flowing onto or near an adjacent strip. Keep the solder within the limits of the strip that is being repaired.

If a strip is burned-out, or fused, cut and remove the damaged strip. Connect a length of insulated wire across the breach or from solder-point to solder-point, as shown in figure 6-20C.

It is best not to glue or bond a conducting strip that has been lifted or peeled from the



70.110
Figure 6-18.—Using a magnifying glass to locate a hairline crack.



70.111
Figure 6-19.—Using a VTVM to locate a break in a conducting strip.

board at a terminal or solder point. Instead, clip off the raised section and replace it with insulated hook-up wire from solder-point to solder-point.

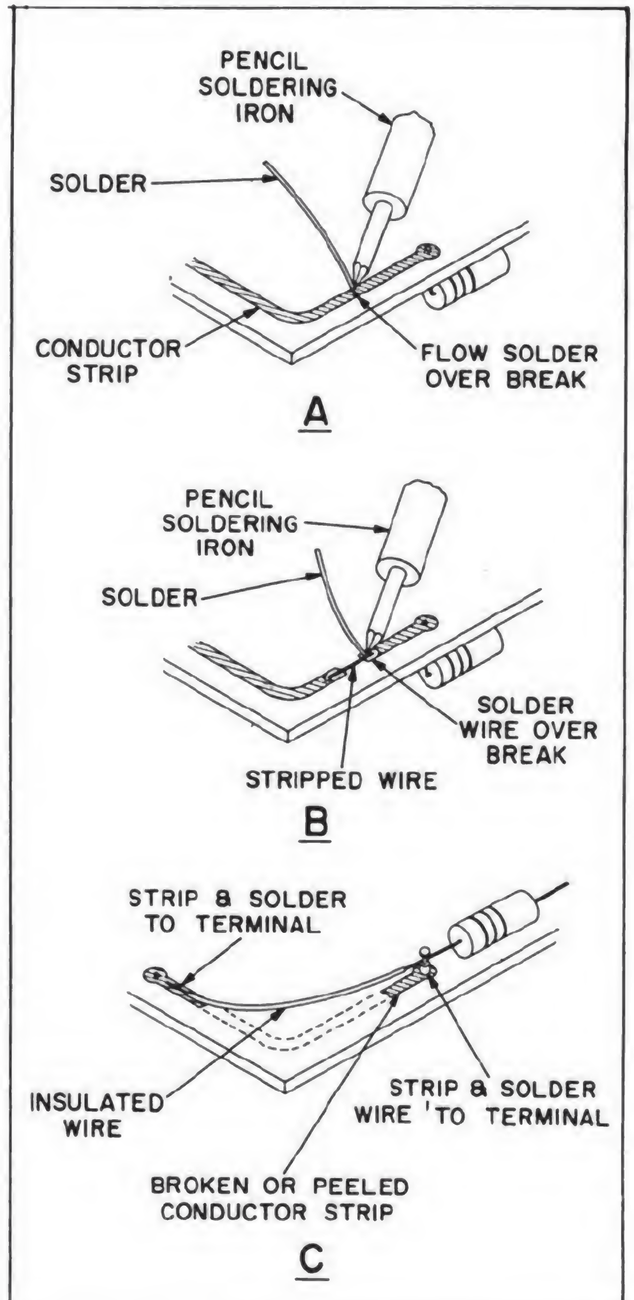
Printed-circuit boards are frequently subject to leakage and shorts, especially if the spacing between conductors is very close, or if careless soldering formed a solder bridge between the conducting strips.

NOTE: After repairs, always scrutinize the board for solder dropping that may cause possible shorts.

LOW RESISTANCE LEAKAGE

Frequently, a low-resistance leakage path will be created by moisture and/or dirt that has carbonized onto the phenolic board. This leakage can be detected by measuring the suspected circuit with a multimeter. To overcome this condition, thoroughly clean the carbonized area with solvent and a stiff brush. If this does not remove it, use a scraping tool (spade end of a solder-aid tool or its equivalent) to remove the carbon, or drill a hole through the leakage path to break the continuity of the leakage. When the drilling method is used, be careful not to drill into a part mounted on the other side.

Occasionally a conductor will rupture or fuse, usually because of a current overload. Generally the rupture, or fusing, is the result of limited spacing and narrow conductors.



70.112
Figure 6-20.—Three methods of repairing broken conducting strips.

Do not try to repair this type of damage, other than to bridge the rupture or fused area, with a length of insulated wire, as shown in figure 6-20C.

GROUNDING STRIPS

Most printed-circuit boards have areas of conduction, known as "grounding conductors," at each edge of the board or on the parts-mounted side of the board. These grounding conductors are conducting strips, used for grounding parts and as a mounting contact for the chassis or common ground. Sometimes an intermittent condition will result if the grounding screws, or mounting screws, become loose. If this occurs, tighten the screws and then solder a good bond directly from the grounding strip to the chassis or equipment ground. If this is not practical, bond the screws (after tightening) with an epoxy resin or similar compound.

COMMON CAUSES OF BROKEN BOARDS

A broken board is probably the most difficult item of a modular assembly to repair. In most instances, especially if the break is large, replacement of the entire board is the only practical solution.

The most common cause of broken boards is droppage. Some boards are broken because of careless handling while the equipment is under repair. Be extremely careful at all times while handling a board. Do not flex the board indiscriminately; be especially careful when removing the board or replacing parts; do not force anything associated with the board.

A printed circuit can be flexed to a certain extent; however, flexing may break the board which must then be replaced at a considerable loss of time. To prevent this possibility, it is always good policy to use a chassis-holding jig or vise when servicing printed-circuit boards.

EMERGENCY REPAIR TECHNIQUES

In many instances there is a need for a time saving technique and procedure for electronic-assembly emergency repair. It is desirable, when making an emergency repair, to avoid disassembling the assembly more than is absolutely necessary to expose the defective part for both testing and repair. Often this can be accomplished by removing only the cover from the assembly.

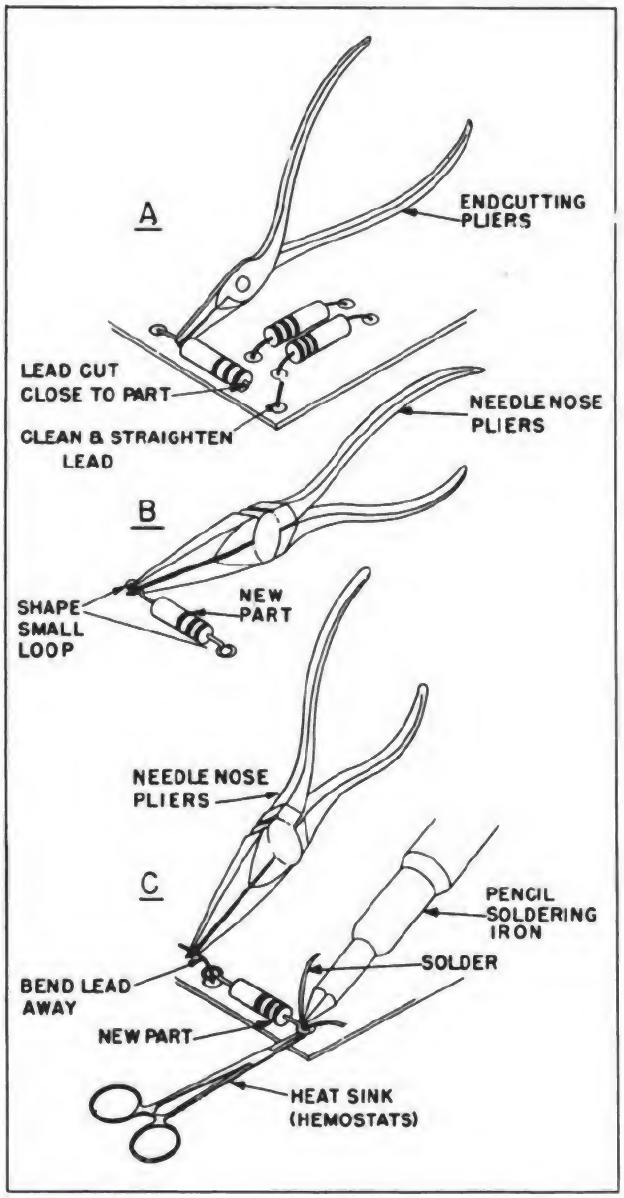
AXIAL-LEAD PARTS REPAIR

To remove and replace an axial-lead part (a part that is mounted by leads that extend from each end, such as a common resistor or capacitor), cut the leads as close as possible to the body of the part, and then connect the leads of the replacement part to the leads remaining on the board. The cutting is accomplished with a pair of end-cutting pliers, as shown in figure 6-21A. Clean and straighten the leads remaining on the board. Fashion small loops in the leads of the replacement part, as shown in figure 6-21B, making the loop size and lead length such that the loops slip easily over the leads projecting from the board. Secure these connections by bending the old leads away from the part. Place a heat-sink clamp on the lead from the board, between the board and the connection to be soldered, and then solder the connection. This is illustrated in figure 6-21C. The heat sink prevents the leads connected to the board from becoming unsoldered and causing a short, or open circuit. Always check to be sure that the old leads are properly connected to the conducting strip.

If cutting the leads of a defective axial-lead part would result in leads that are too short for the replacement part to be connected properly, cut the faulty part in half with a pair of diagonal or end-cutting pliers, as shown in figure 6-22A. Then carefully cut away the pieces of the part from each lead, as shown in figure 6-22B. This will yield leads of sufficient length to permit the replacement part to be fitted and soldered.

TERMINAL AND STANDOFF PARTS REPAIR

Considerable care must be taken when replacing a defective part that terminates on miniaturized standoffs, feadthrough terminals, and the like. These small terminals break easily from applied pressure (too heavy an application when applying a tool or soldering iron) or they may melt loose from excessive application of the hot soldering iron. Do not attempt this type of repair on an assembly unless there is no replacement available. For



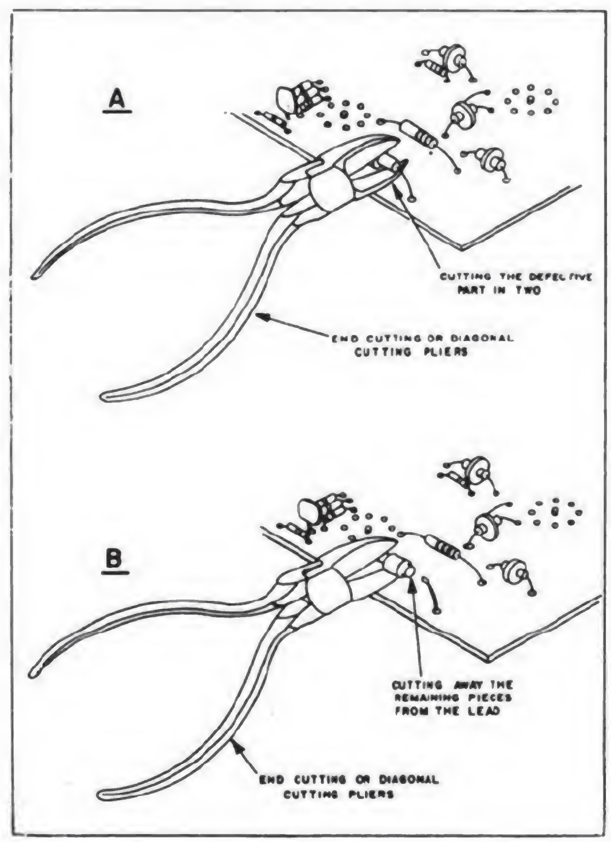
70.116
Figure 6-21.—Replacing a defective part by cutting its leads.

emergency or temporary repair purposes, the following techniques may be used: Cut the lead close to the defective part, as shown in figure 6-23A. Use a heat-sink clamp (or pliers) next to the terminal, and then solder a spliced lead from the terminal to the new part, as shown in figure 6-23B.

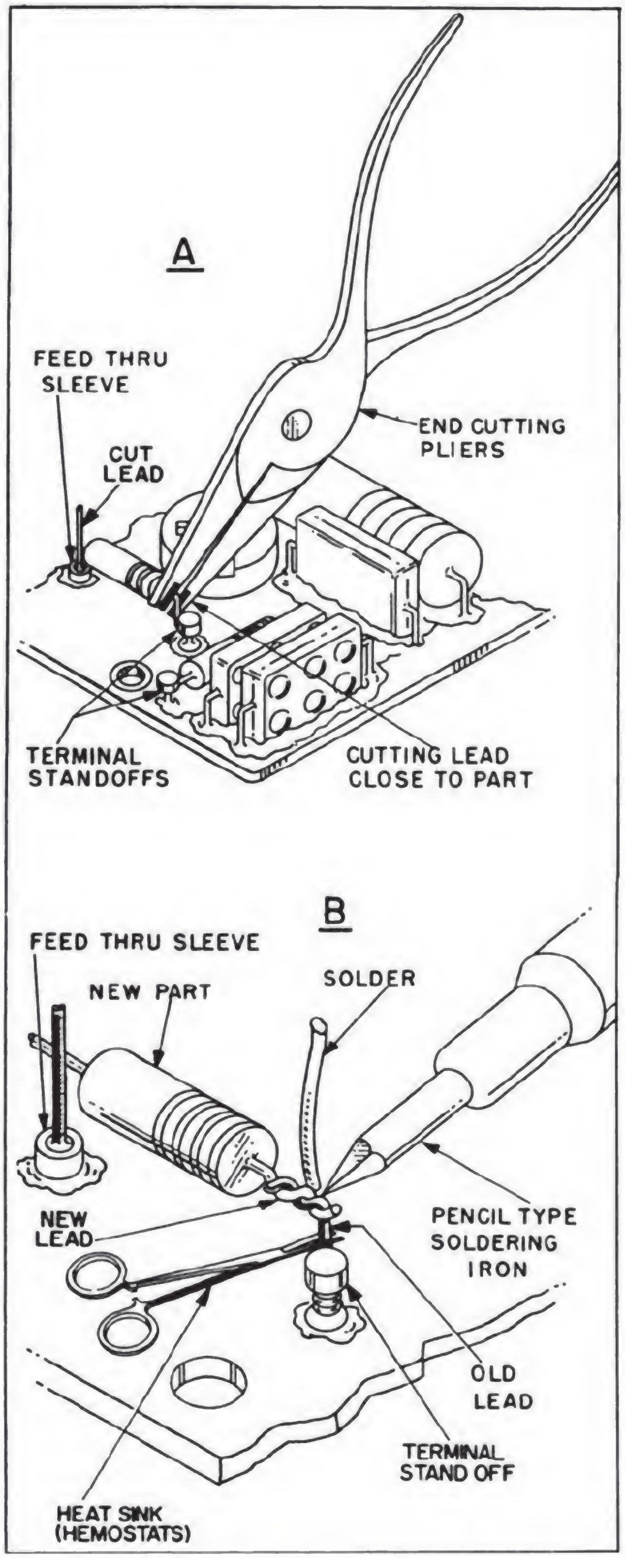
A helpful heat-control technique is to place a small piece of beeswax (Fed Spec No. W9160-253-1172) on the terminal behind the heat sink. When the beeswax melts, the temperature limit has been reached. This is a warning to remove the source of heat immediately. Allow the area to cool thoroughly before attempting to complete the soldering of the connection. Apply a new piece of beeswax to the terminal, repeating this procedure until the connection is satisfactorily soldered.

BONDING CONDUCTIVE STRIPS

It is best not to glue or bond a conducting strip on a printed-circuit board that has been lifted or peeled from the board at a terminal or solder point. Instead, clip off the raised section and replace it with insulated hook-up wire from solder-point to solder-point. However, for temporary or emergency repair, a loose or peeled strip may be bonded back onto



70.117
Figure 6-22.—Cutting the defective part for minimum lead length.



70.118
Figure 6-23.—Removing a defective part from a miniature standoff terminal.

the board using a nonconductive bonding compound (Eccobond "55" epoxy adhesive, by Emerson & Cuming Co., Canton, Mass., or its equivalent). A silver conductive paint (Part No. 21-1 Silver Print Conductive coating, General Cement Mfg. Co.), or similar material can also be used to repair printed-circuit conducting strips. This technique is satisfactory for temporary or emergency repair, but is not satisfactory for permanent repair.

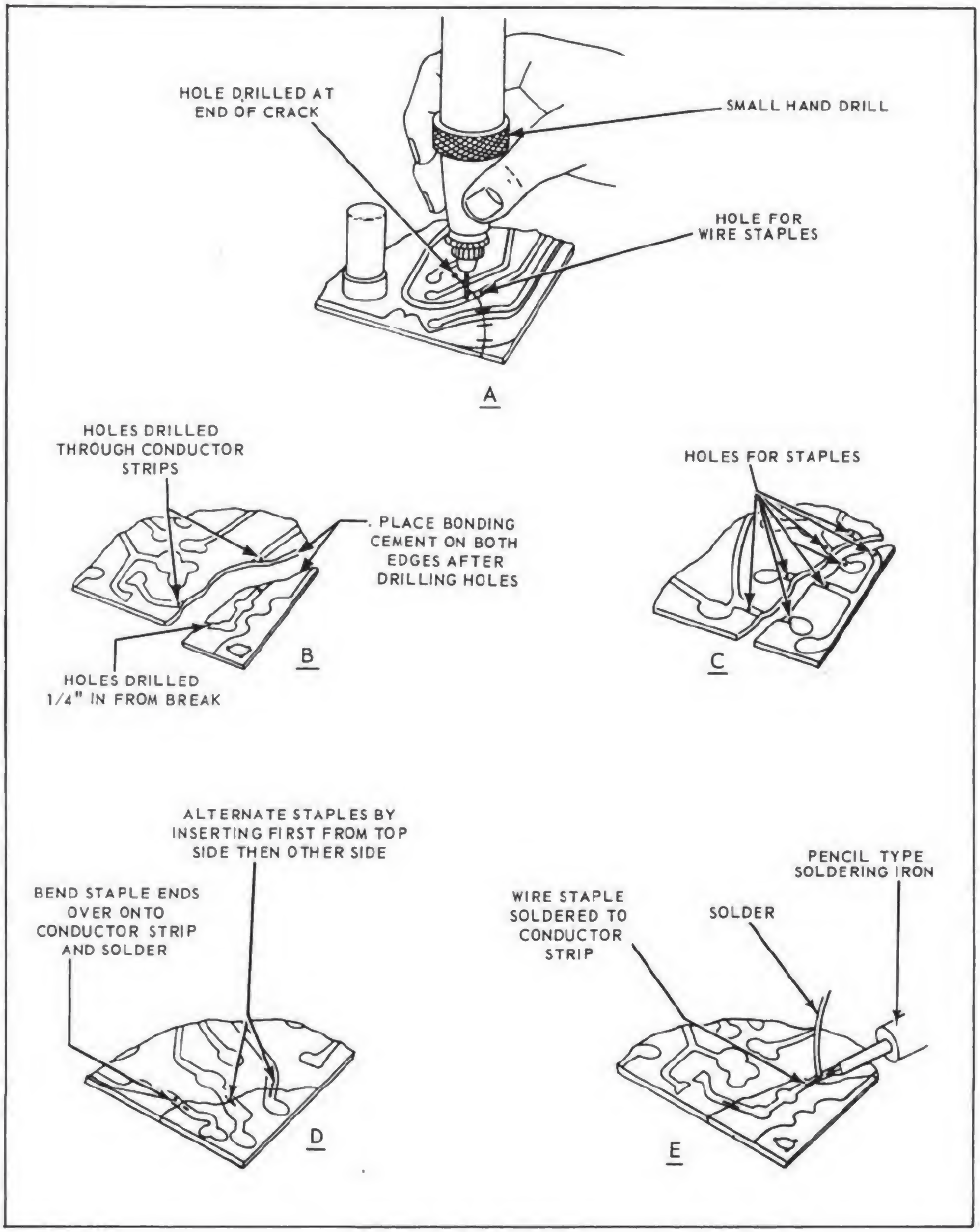
BROKEN PRINTED-CIRCUIT BOARD REPAIR

A broken printed-circuit board may have to be repaired in an emergency (temporary status) where no replacement is available. Before repairing a broken printed-circuit board, assess the damage for the extent of the break and the amount of damage to the parts involved. If the board is not too complicated or the damage too extensive, the board can probably be repaired.

If a small portion or supporting corner of the board is broken off, it may be rebonded to the large section with a nonconductive cement (Eccobond "55" epoxy adhesive, or its equivalent). If cementing is not feasible or does not hold satisfactorily, the pieces can be fastened together with wire staples, cut from solid conducting wire of the diameter and length required, depending on the width of the conducting strip to be repaired.

To insert the staples, drill holes about 1/4 inch in from each side of the break, as shown in figure 6-24A, B and C. The holes should be just large enough to accommodate the wire used for stapling. (This may vary, depending on the width of the conductive strip to be repaired.) Drill the holes through the conducting strips so that the staples will provide a good electrical contact across the break; this method will permit the use of enough staples to hold the pieces together without danger to shorts between conductors. If the break is sufficiently large, position additional staples at all points possible to give the board more support.

Where the adhesive and stapling method described above does not provide structural strength of sufficient rigidity, consideration should be given to the use of splints or a doubler. Strips of thin-card material are glued across the fracture by means of nonconductive adhesive material. Where additional



70.119

Figure 6-24.—Repairing a broken printed circuit board.

strength is considered necessary it may be obtained by gluing a plate of the card material to the splints by means of the nonconductive adhesive.

Rebond any loose conducting strips with a nonconductive bonding cement; then apply nonconductive cement to both sides of the break, and join the sections together, as shown in figure 6-24B. Insert half of the measured and precut wire staples from top to bottom, and the other half from bottom to top, bending the ends flush against the board, as shown in figure 6-24D. Solder these staples to the conducting strip, as shown in figure 6-24E.

If the board is not completely broken but is only cracked, drill a hole at the end of each crack, as shown in figure 6-24A to prevent further lengthening of the break. Then repair the crack in the same manner as the complete break discussed above.

After the repairs are completed, clean both sides of the repaired area with a stiff brush and solvent. Allow the board to dry thoroughly, then coat the repaired area with an epoxy resin or similar compound. This coating not only will protect the repaired area, but will help to strengthen it.

NOTE: When a board is broken, it is much better to replace the entire board. The repair techniques given above are for emergency repair only.

CHAPTER 7

ELECTRONIC INSTALLATIONS AND MAINTENANCE PROCEDURES

This section of the chapter acquaints the prospective CT M with some of the problems involved in the installation of electronic equipment and with some of the methods employed to overcome these problems; it is not intended to be an installation handbook. It will help the beginning technician to become better acquainted with the electronic equipment used and with the way it is installed.

Some general information on cabling and the use of stuffing tubes and kickpipes, as well as the use of insulating materials, is included because each of these items bears a direct relationship to electronic equipment. Information is also included on moisture-absorbing materials such as silica gel.

The types, use, and location of electric filters are important and some general information on types and locations is included in this chapter.

Methods of installing electronic equipment (and the reasons why certain equipments are installed as they are) are important to the CT M and are also included.

POWER CABLING

Types of Power Cables

The operation of various electronic equipment on board will depend on the power supplied. This power is distributed to the electronics spaces by a system of cables. The CT M should know in detail the location and characteristics of the cabling which supplies the equipment with which he works.

He should become familiar with the current-carrying capacity of cables; their insulation strength; and their ability to withstand heat, cold, dryness, bending, crushing, vibration, twisting, and shock. Several types of cables are used in the applications under discussion, with design characteristics suited to their location purpose.

Type SGA (Shipboard, General use, Armored) cables are designed to have a minimum diameter and weight consistent with service requirements in fixed wireways. This type supersedes the older, widely used type HFA (Heat and Flame resistant, Armored) cable.

Type SSGA cable (fig. 7-1) consists of stranded copper conductors (in this case, only one conductor-indicated by the "S" before SGA) insulated with silicone rubber and glass fibers around which is placed an impervious sheath. The sheath is covered with braided metal armor, and then a coat of paint is applied.

The SGA cables are designated as follows: (1) SSGA, single conductor; (2) DSGA, twin (double) conductor; (3) TSGA, three conductor; and (4) FSGA, four conductor.

The HFA cables (also composed of stranded copper conductors) are designated as follows: (1) SHFA, single conductor; (2) DHFA, twin (double) conductor; (3) THFA, three conductor; (4) FHFA, four conductor; and (5) MHFA, multiconductor.

Twisted-pair telephone cables are designated as TTHFWA.

Many applications will require cables that can be bent and twisted again and again without damaging the conductor insulation or the protective

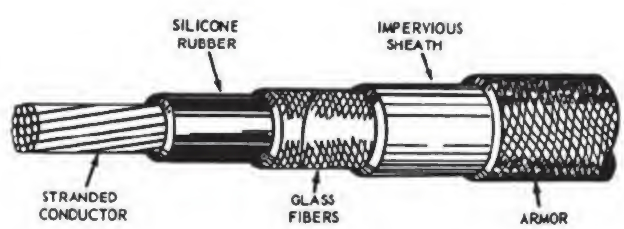


Figure 7-1.—SSGA cable.

covering. For such applications, flexible cables are used.

Flexible cables have synthetic rubber or synthetic resin insulation and a flexible sheath that is resistant to water, oil, heat, and flame. However, these cables are not as heat and flame resistant as armored HFA and SGA cables. Flexible cables for general use are designated by the letters, HOF-for example, DHOF, THOF, and FHOF. Flexible cables for limited use are designated by the letters COP-for example, DCOP, TCOP, and FCOP.

Other types of cables used in electronics work are:

1. DRHLA-Double conductor, radio high-tension, lead armored.
2. FHFTA-Four conductor, heat and flame resistant, thin-walled armor.
3. MCSP-Multiple conductor, shielded, pressure resistant (submarine applications).
4. TTRSA-Twisted-pair telephone, radio shielded, armored (characteristic impedance approximately 76 ohms).

Designation of Conductor Size

Generally, when the size of the individual conductors contained in the cables is indicated in the cable designation, the numeral (or numerals) following the letter designation indicate the approximate cross-sectional area of the individual conductors in thousands of circular mils to the nearest thousands. For example, TSGA-60 is a 3-conductor armored cable for general shipboard use, with each conductor having a cross-sectional area of 60,090 circular mils. However, when the numerals immediately following the letter designation indicate the number of conductors comprising the cable, the size of the individual conductors may be indicated by additional numerals enclosed in parenthesis. For example, MDGA-19(6) is a 19-conductor electrical power cable for shipboard nonflexing service, with each conductor having a cross-sectional area of 6,512 circular mils.

Multiple-Conductor Cable Designations

Multiple-conductor cable types and class designations are followed by a number that indicates the number of conductors. For example, MSCA-30 is a heat and flame resistant armored cable with 30 conductors.

For telephone cable, the number indicates twisted pairs. For example, TTHFWA-25 means that the cable contains 25 twisted pairs; TTRSA-4 means that the cable contains 4 pairs individually shielded.

Selection and Installation of Cables

The CT M will, in all probability, be called upon to install power cables. There are at least five items that must be considered when power cables are installed. They are (1) the maximum connected load in amperes, (2) the possible added load due to future installations, (3) the demand factor (that is, the average demand in amperes over a 15-minute interval divided by the total connected load in amperes), (4) the cable service rating (the physical characteristics required for a given type of service), and (5) the maximum allowable voltage drop in the part of the circuit under consideration.

The current-carrying capacity and voltage-drop limitations determine the cable size for a particular application. The current capacity is dependent upon the type and size of the conductor, the permissible temperature rise, and the physical characteristics of the space in which the cable is installed. The allowable voltage drop depends on the type of load connected to the circuit.

All connections to cables are made in standard appliances and fittings; splice connections are not made. However, cable splices are permitted as an emergency repair and on a limited basis (by repair activities) where it has been determined that time and replacement cost is excessive, and existing cable is in good condition. Where cables pass through decks and watertight bulkheads, stuffing tubes are used. Cables passing through decks are protected from mechanical injury by kickpipes or riser boxes.

FILTERS

Modern electonic receiving equipments are being made with greater sensitivities, and this has increased the problem of radio interference generated by electromechanical devices such as motors, generators, relays, and the like. Likewise, the interactions between the various equipments can cause major interference problems.

Good installation practices will reduce or perhaps eliminate radio interference, but a filter may be needed to reduce certain types of interference to a tolerable level.

Radio Interference

The major sources of radio interference are summarized as follows:

1. ATMOSPHERIC NOISE is caused primarily by lightning. The reduction of this noise is accomplished by the use of noise limiters and f-m.
2. PRECIPITATION STATIC is a problem chiefly in aircraft caused by static discharges and corona on snow, dust, rain, or similar substances. It is identified by a frying sound. Special measures are needed for its reduction or elimination. Proper grounding of equipments and structures will generally reduce this type of disturbance below the nuisance level.
3. BACKGROUND NOISE is due largely to shot effect (bombardment of the tube elements by irregularly spaced bunches of electrons), thermal noise (agitation of electrons in resistances because of heat), and microphonic noise (generally due to vibration of electron-tube elements).
4. COSMIC NOISE is the result of radiations from space. It is fast becoming a limiting factor in the design of more sensitive receivers.
5. MAN-MADE NOISE may be generated by a variety of sources. These sources include rotating electrical machinery, ignition systems, relays, pulse-type equipment (for example, radars), interaction between equipments, diathermy (also induction heating and welding) equipment, hum pick-up at power or audio frequencies, and systems employing ionization of gas vapors.
6. Another type of interference that must be dealt with is that caused by operating several receivers from one antenna, as in multicoupler installations. Various combinations of filters are used to feed the appropriate frequencies to the various receivers.

Signal or Noise Interference

Signal or noise interference may be transferred from one circuit to another by several means. They include:

1. CAPACITIVE or ELECTROSTATIC coupling in which one circuit is linked to another by means of a capacitance that is common to both. This is especially true at radio frequencies.
2. INDUCTIVE or ELECTROMAGNETIC coupling in which a conductor is present in the electromagnetic field set up by the noise interference. This type is the hardest to isolate.
3. DIRECT RADIATION, which involves essentially the same principle as radiation from a transmitting antenna to a receiving antenna.
4. CONDUCTION ALONG LINES, which is the transfer of r-f energy along a conductor. It is this flow of signal or noise energy that is coupled by the methods mentioned in the last three paragraphs.

Conductive coupling (conduction along lines) can be reduced or eliminated by the use of the filter or filter network at the noise source (fig. 7-2).

Types of Filters

ATTENUATION is the amount that the signal or noise voltage is reduced in a filter. It is measured in decibels (db). Decibels are discussed in Basic Electronics, NavPers 10087-A. Band-pass and band-elimination filters are also discussed in the same training course. See figure 7-3 for an illustration of the terms used in describing filters.

PASS BAND is the frequency range over which the filter passes signals with minimum attenuation.

STOP BAND is the frequency range over which the filter attenuates the applied signal.

CUTOFF FREQUENCY is the frequency at which the filter changes from a pass-band to a stop-band filter or vice versa.

LOW-PASS FILTER.—The low-pass filter passes all frequencies from zero frequency (fig. 7-4A) (dc) up to the cutvff frequency (fc). All power lead filters fall in this class. For example, if it is desirable to pass 60-cycle power and to attenuate noise frequencies above (for example) 150 kc, a low-pass filter having a cutoff frequency of approximately 50 kc, may be used.

HIGH-PASS FILTER.—The high-pass filter attenuates all frequencies from zero frequency to the cutoff frequency and passes all frequencies above the cutoff frequency (fig. 7-4B).

BAND-PASS FILTER.—This filter passes all frequencies within a specified range and attenuates all other frequencies (fig. 7-4C). Band-pass filters have special applications and are seldom used for noise elimination. One form of band-pass filter is the crystal filter used in communications receivers.

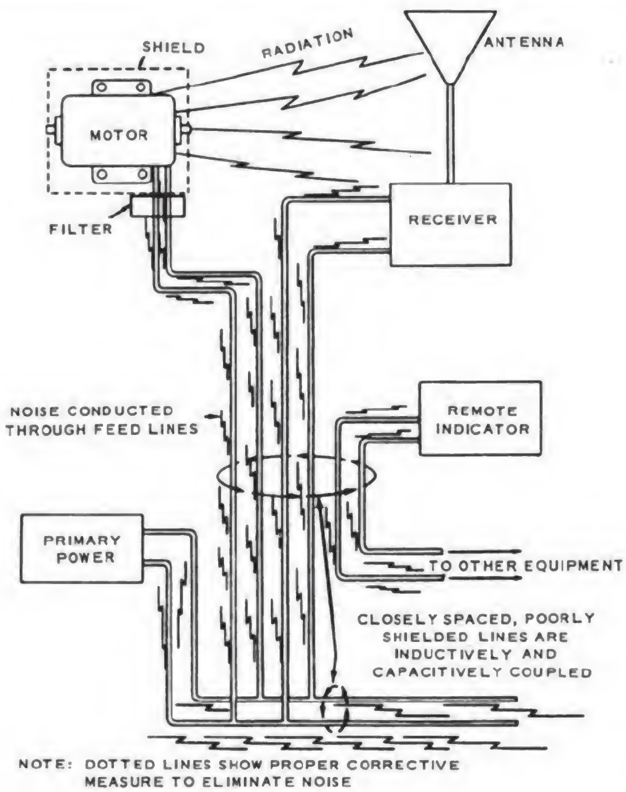


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Figure 7-2.—Radio noise coupling showing position of filter for noise elimination.

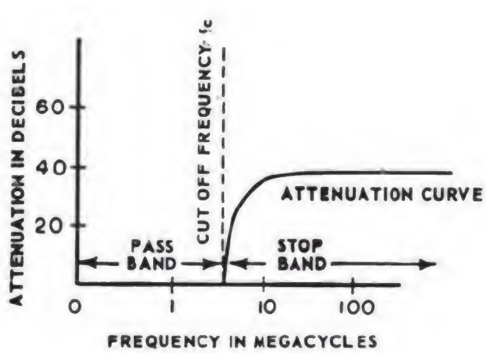

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Figure 7-3.—Illustration of the terms used in filters.

BAND-ELIMINATION FILTER. — This filter attenuates a band of frequencies and passes all other frequencies (fig. 7-4D). It is most commonly used as a simple wave trap or absorption filter. Several wave traps are used in a television receiver.

Schematic diagrams of low-pass and high-pass filters are shown in figure 7-5.

Location and Installation of Filters

Filtering is done at the noise source whenever it is possible and practicable. This eliminates or reduces to an acceptable level all interference caused by the noise source. However, it may be impracticable to filter at the source in the following cases:

1. When the source is an antenna that interferes with other antennas under operating conditions.
2. When the source feeds many multiconductor cables and a filter would be required on every cable.
3. When the source is poorly shielded.

Schematic diagrams of three types of power-line filters are shown in figure 7-6. Filters may be mounted on bulkheads or on equipments.

The method of mounting a filter so that a bulkhead, chassis, or equipment case acts as an isolating shield between the input and output of the filter is referred to as bulkhead mounting. Very often filters that are to be used in a component piece of equipment are designed to lend themselves to this type of mounting. Figure 7-7 shows some typical filter installations of this type. This same principle may be applied to filters enclosed in a box mounted on the side of the equipment. It does not lend itself to water-tight installations because the space through which the leads pass into the equipment cannot be effectively sealed.

Typical installations of filters mounted on machines or other noise sources are illustrated in figure 7-8. Much additional valuable information is included in Chapter 21 of the Electronic Installation Practices Manual, NavShips 900,171.

A good r-f connection is exceedingly important in filter installations regardless of whether it is a joint, a grounding surface, or a shield contact. Clean, continuous r-f surfaces must be maintained throughout the installation with all connections at painted surfaces scraped to the bare metal.

Low-pass filters are used on many radio receivers-for example, the AN/URR-35. Figure 7-9 shows a rear (upside down) view of the low-pass filter used with the AN/URR-35.

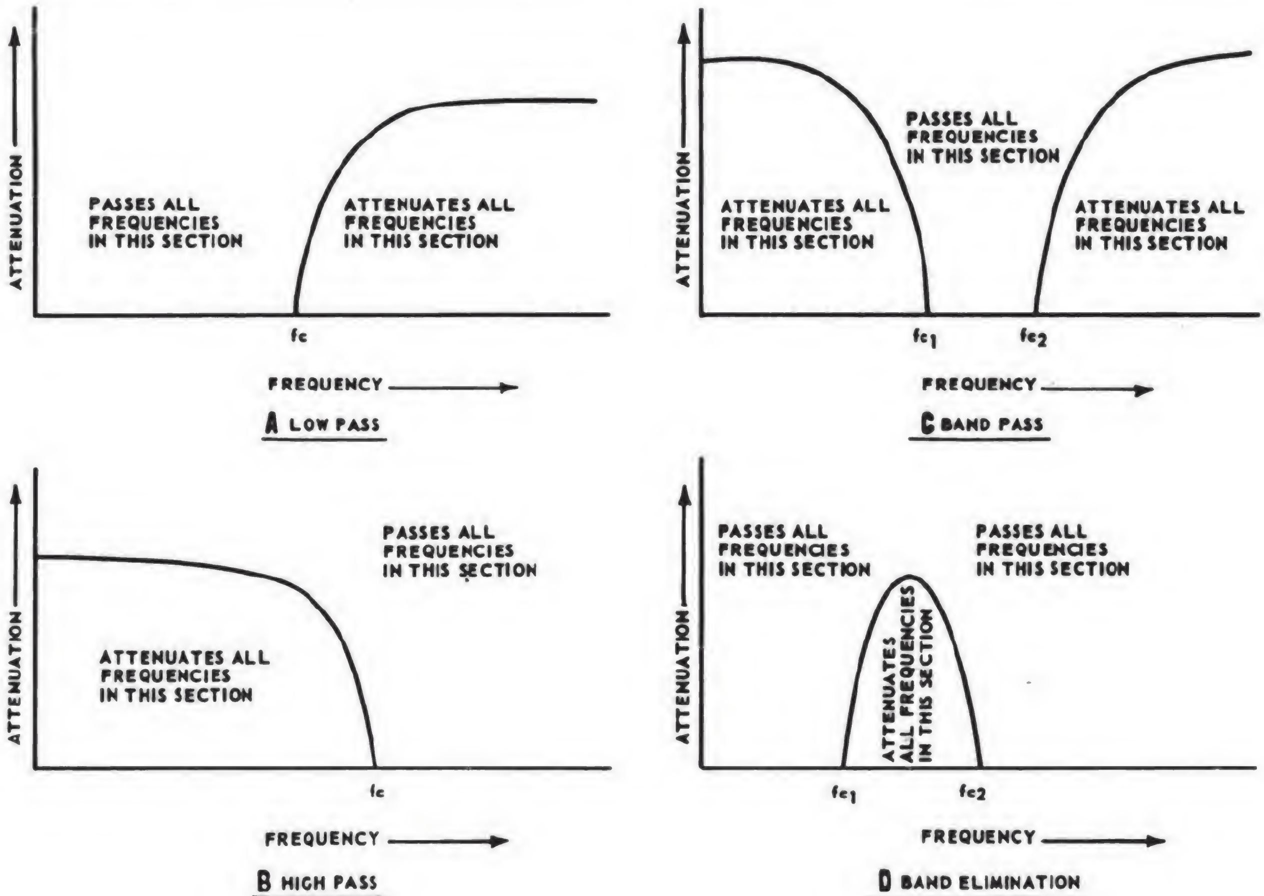

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Figure 7-4.—Filter response curves.

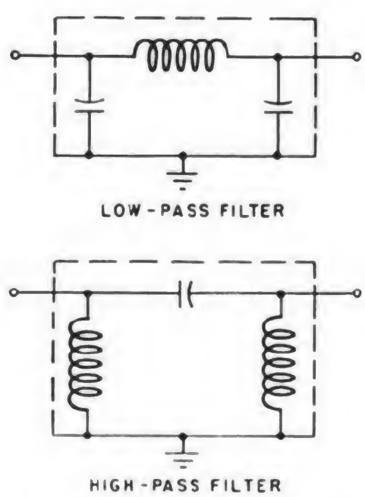

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Figure 7-5.—Low-pass and high-pass filters.

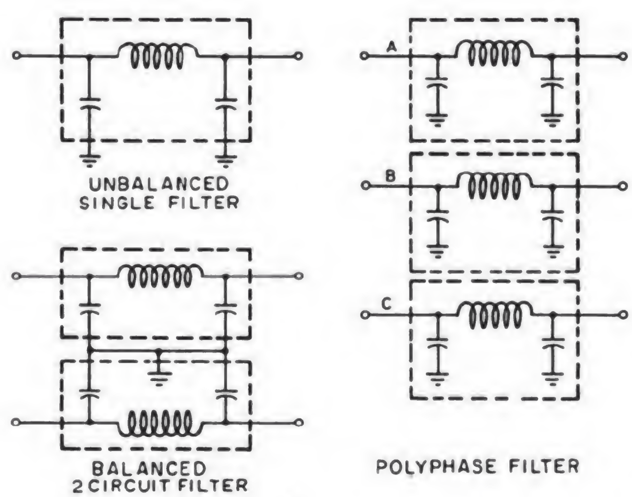

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Figure 7-6.—Types of power-line filters.

The schematic diagram of this filter is shown in figure 7-10. The filter allows the necessary connections into and out of the rear of the receiver, but eliminates unwanted signals from passing through the lines. There are three main circuits through the filter: the antenna lead, the a-c power lead, and the audio output lead.

R-f signals from an antenna are brought through a coaxial lead and connected to the antenna jack. They pass through the low-pass filter to the r-f amplifier unit.

Power for the receiver is connected to the power jack. The two-section, r-f filter eliminates any r-f energy that may tend to come in through the power lines. After passing through the filter, the power is fed to the receiver through terminals 70 and 71.

The audio signal from the receiver output transformer is connected through terminals

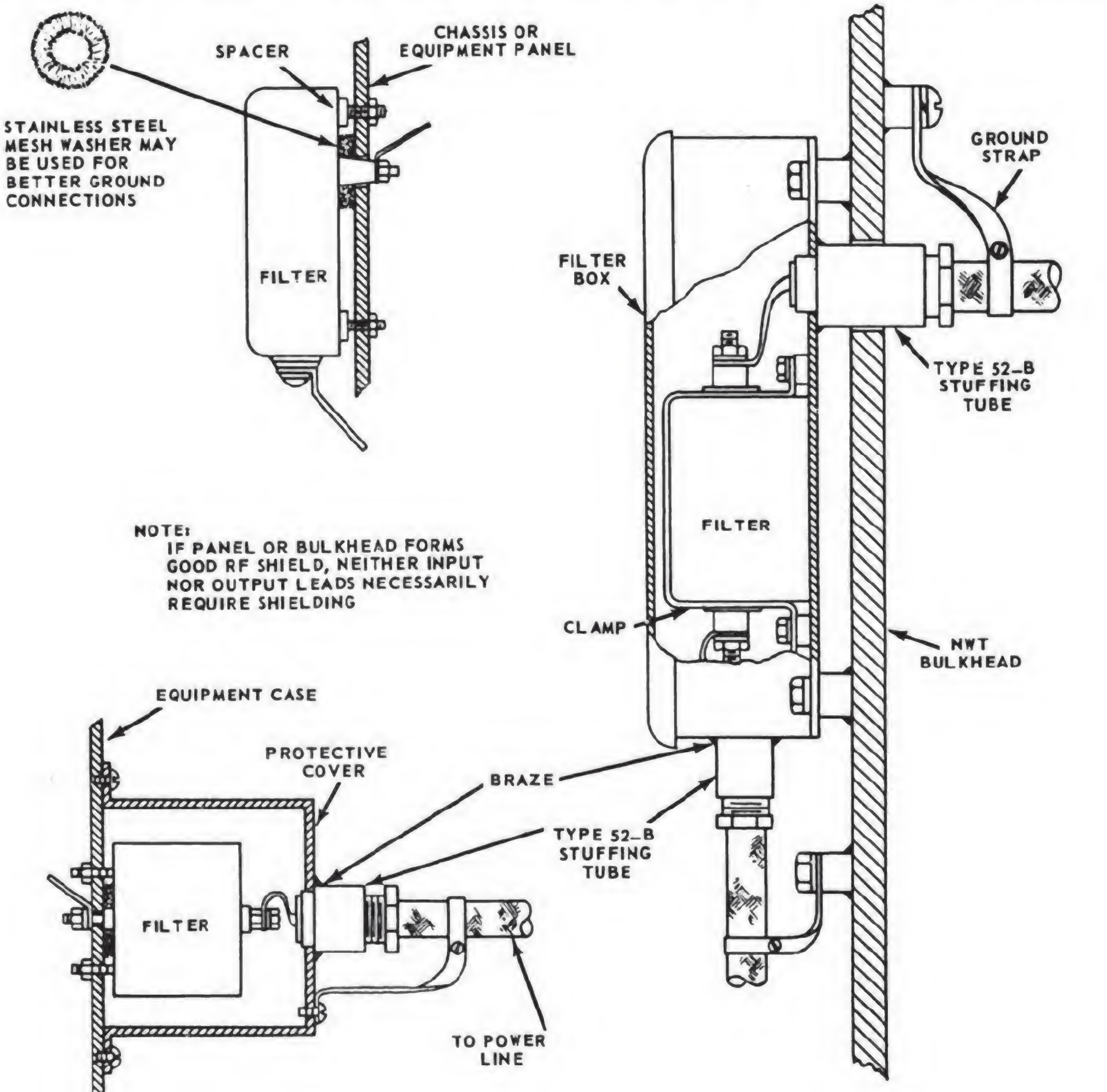

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Figure 7-7.—Typical installations using bulkhead mountings.

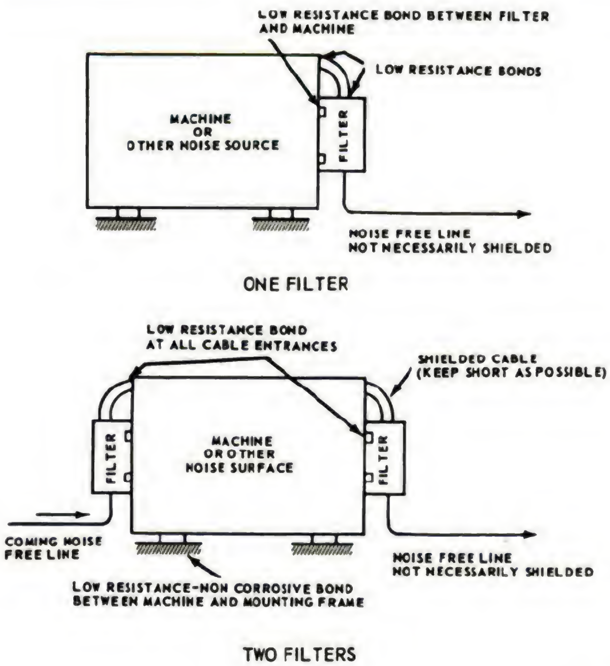

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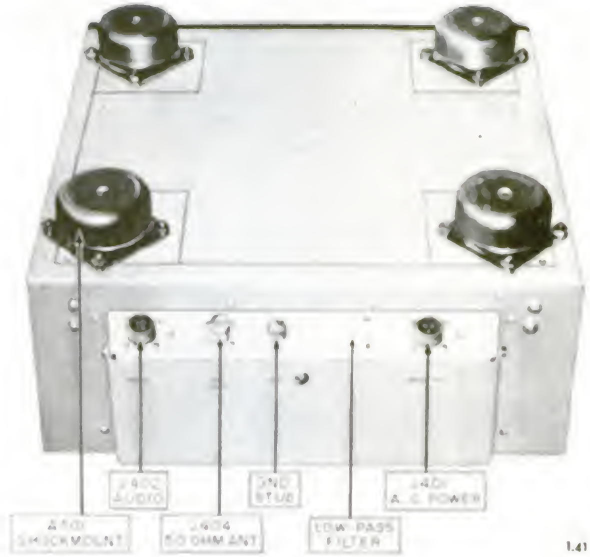
Figure 7-8.—Low-pass filter installations on a machine or other noise sources.



1.41

Figure 7-9.—Low-pass filter used with the AN/URR-35 radio receiver.

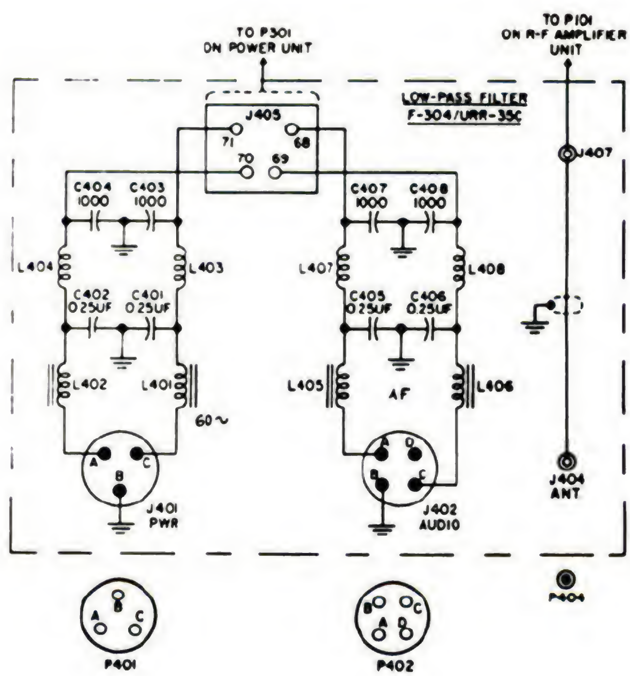


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Figure 7-10.—Schematic diagram of the low-pass filter used with the AN/URR-35 radio receiver.

68 and 69 to the low-pass filter. The audio signals then pass through the two-section filter to the audio output. The filter allows the audio signals to pass through, but prevents any feeding back of r-f signals through the audio lines from outside the receiver.

GROUNDING OF ELECTRONIC EQUIPMENT

The proper grounding of electronic equipment is one of the most important steps in the installation procedure. Even during routine checks, tests should be made to ensure that all equipment is properly grounded. The following information is quoted from NavShips 900,171.

"All units of electronic equipment whose d-c resistance from case to ground exceeds 0.01 ohm (10 milliohms) shall be grounded by the use of straps as follows:

1. On units requiring sound isolation, the straps shall be copper braid, not less than 1/2 inch wide.

2. On other units, the strap shall be not less than 0.020 inch thick by 1/2 inch wide, sheet copper or brass.

3. The surface at the point of attachment of the straps shall be thoroughly cleaned to ensure metal-to-metal contact.
4. The straps shall be as short as possible with only enough loop allowed to permit satisfactory deflection of shock or isolation mounts.
5. The strap connections shall be locked to prevent loosening from vibration.
6. Only one strap wire is required for each unit unless tests indicate more are needed."

The proper grounding procedure is equally as important for shielded cables and other components as it is for electronic equipment.

RIGID R-F TRANSMISSION LINES

Construction

Rigid r-f transmission lines include waveguides (rigid and flexible), bead-supported coax (teflon and steatite), stub-supported coax, and pyrotenax cable.

Rigid waveguides may be round or rectangular in shape; however, the use of round waveguides is limited to special applications, such as rotating joints. Rectangular waveguides are widely used in radar and microwave applications.

Waveguides are generally designated by size; and table 7-1 lists some of the more common sizes.

Table 7-1.—Commonly Used Sizes of Rigid Waveguide.

Size (inches)	Radar Band	Frequency Band
6-1/2 x 3-1/4	L	UHF
3 x 1-1/2	S	UHF/SHF
1-1/4 x 5/8	X	SHF
1 x 1/2	X (small)	SHF
5/8 x 5/16	K	SHF/EHF

Flexible waveguides have greater power loss than rigid waveguides, and therefore the flexible type is seldom used except where there is considerable vibration.

Bead-supported coax was used on early radar equipment installations and is still necessary in certain types of installations.

Stub supported coax was more widely used on early radar equipment installations; and short runs are still found in late equipments, usually within the antenna pedestal.

Pyrotenax coax r-f cables have a solid copper inner conductor, a seamless copper outer conductor, and a tightly packed powdered magnesium oxide dielectric. They are fireproof and pressure proof, and are designed for installations where these properties are important.

The proper type and size of waveguide is determined by the equipment designer, and no change is made without the approval of the Bureau of Ships.

Installation

Many factors are considered when a waveguide is installed. However, two of the most important considerations are: (1) the range of the equipment depends on the height of the antenna and (2) a great deal of energy is lost when the length of the waveguide is increased by a small amount (over one-half of the power may be lost in a 50-ft run).

The method of installation is equally important. For example, sharp bends, dents, and foreign materials in the guide will cause serious attenuation of the signal (see chapter 11 of NavShips 900,171).

From these considerations it may be seen that there is an optimum height beyond which additional waveguide length will defeat its own purpose.

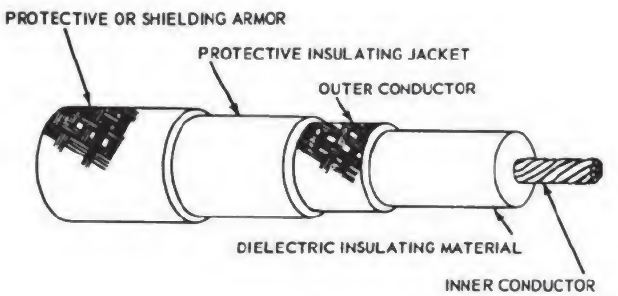
FLEXIBLE R-F TRANSMISSION LINES

Construction

Flexible radiofrequency transmission lines (coax) are two conductor cables, one conductor of which is concentrically contained within the other, as illustrated in figure 7-11. Both conductors are essential for efficient operation of the transmission line. Of course, the proper connectors and terminations are also necessary for efficient operation of the line.

The inner conductor may be either solid or stranded and may be made of unplated copper, tinned copper, or silver-plated copper. Special alloys may be used for special cables.

The dielectric insulating material is usually polyethylene or teflon, although neoprene or other rubber-like materials are occasionally used for pulse cables. (pulse cables carry d-c pulses that may have relatively high voltages during a relatively short pulse time).



1.43
Figure 7-11.—Construction of flexible r-f transmission line.

Braided copper is usually used for the outer conductor; it may be tinned, silver plated or bare. The outer conductor is chosen to give the best electrical qualities consistent with maximum flexibility.

The protective insulating jacket is usually a synthetic plastic material (vinyl resin). Neoprene rubber is generally used on pulse cable; silicone rubber jackets are being used for high-temperature applications.

Armor is needed for protection. It may be braided aluminum or sometimes galvanized steel, similar to that used on power cables.

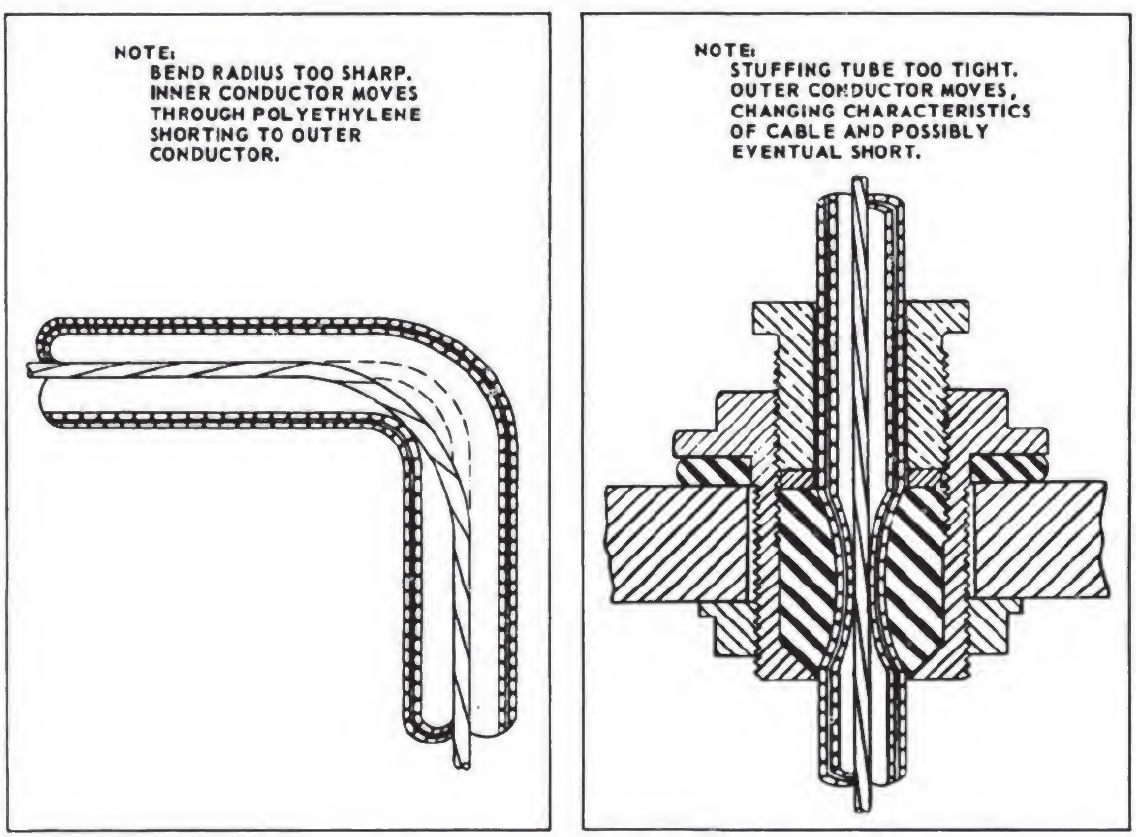
R-F cables may look like power cables, but they require special handling and careful installation. These cables are vital to the proper operation of all electronic equipment and therefore must be installed and maintained with the greatest care.

Classification By Dielectric

The three common types of dielectric are polyethylene, teflon, and synthetic rubber.

Polyethylene is a gray, translucent material. Although it is tough under general usage, it will soften when subjected to heavy pressure for a period of time. Two possible effects of bad installations are illustrated in figure 7-12.

Teflon is a white opaque plastic material. This material will withstand high temperatures



1.44
Figure 7-12.—Effects of bad installations.

and will remain flexible at relatively low temperatures. It has a very low coefficient of friction and of adhesion. Therefore, most materials will not stick to teflon. It is unaffected by the usual solvents.

Synthetic rubber (neoprene) is black and very flexible. It has high power loss at high frequencies and therefore is not used in cables carrying r-f energy. However, it is used for transmitting high-voltage d-c pulses. Because of its flexibility and ability to "stick" to metals, it forms very tightly around the conductors and minimizes corona (high-voltage breakdown of the air surrounding a conductor). (A listing of radio-frequency cables and their related physical characteristics and pertinent data is given in appendix IV.)

Location and Length of Cable Runs

Wherever possible, high-temperature locations are avoided. Pulse cables are run separately, when possible, to reduce coupling and interference.

Because attenuation (power loss) in a line increases with its length, cables are kept as short as practicable, consistent with avoiding high-temperature locations, sharp bends, and strain on the cable. (See chapter 10 of NavShips 900,171 for additional information.)

If the equipment is shock mounted, enough slack in the cable is allowed to permit unrestricted motion of the equipment. The cable may be wrapped with friction tape for a distance of three or four inches from a point under the last cable clamp in the direction of the equipment. This eases the bending of the cable at that point and reduces the possibility of cable deformation because of constant vibration.

When cables are connected to equipment that slides out for maintenance, extra slack is provided.

Installation of Cables

Flexible cables are flexible only in the sense that they will assume a relatively long bend radius. They are not intended to be stretched, compressed, or twisted; and they are installed with this in mind. Bends are made as large as practicable, the radius of the bend being greater than 10 times the diameter of the cable.

The number of connectors are generally kept to a minimum to reduce line losses and maintenance problems.

Fabricated straps are used for holding the cables. They are snug, but not too tight. Back straps (which keep the cable away from a surface) are used in making cable runs in compartments that are subject to sweating. In more recent installations semicontour straps and cable bands are used for certain applications.

The exact methods of installing cables are included in Chapter 9 of the Electronics Installation Practices Manual, NavShips 900,171.

Although the installation of r-f cables is not the primary duty of a CT M, he nevertheless has to live with and depend on them all of the time. Therefore he should have some knowledge of good installation practices. Some important points to remember are: (1) do not change the physical dimensions of a cable because this will change the electrical property; (2) remember that a damaged insulating jacket may allow water into the cable and cause a short at the connector; (3) avoid putting a strain on a cable, and (4) avoid exposing the cable to abrasion by the use of the necessary grommets, sleeving, tape and the like.

Splicing cables and installing fittings require special skill. Instructions are given in Chapter 10 of Electronic Installation Practices Manual, NavShips 900,171.

ANTENNA SYSTEMS

The following paragraphs are included to give the CT M information about installation of shipboard antennas and antenna transmission lines.

Long Wire Antennas

The whip and dipole antenna assemblies are displacing the long wire antenna for shipboard installations. However, the long wire antenna is still used on some installations and is often used as an emergency antenna.

Antenna wire is usually a stranded, bare, phosphor or silicon-bronze wire. For transmitting, a 5/16-inch diameter wire is commonly used; and a 1/8-inch diameter wire is commonly used for receiving. The wire is continuous from the entrance insulator to the far end. Good installation practice requires that it be free from splices, knicks, sharp bends, deformed spots, and broken strands. The length, of course, depends on the frequency that is being transmitted, the space that is available, and other considerations.

In addition to the necessary wire, an antenna installation requires such items as supporting insulators, turn-buckles, clamps, shackles, safety links, staples, and pad eyes.

A typical long wire antenna installation is illustrated in figure 7-13. The methods of installing antennas are included in Chapter 2 of Shipboard Antenna Details, NavShips 900121(A).

Whip Antennas

Whip antennas give a neater appearance, and in restricted areas they are a practical necessity. Because whip antennas are essentially self-supporting, they may be installed in many locations. They may be deck mounted or mounted on brackets on the stacks, superstructure, or similar location. If a stack is used, the outer casing will usually have to be reinforced to support the added weight and stress. When the whip antenna is installed on a stack, it is usually mounted near the top and approximately 24 inches away from the stack. In all installations of whip antennas, allowance is made for swaying of the whip. The whip is mounted in a clear space where it cannot strike other objects.

Whip antennas that are used for receiving only are mounted away from the transmitting antennas so that a minimum of energy from the transmitter will be picked up.

The preferred method of mounting whip antennas is shown in figure 7-14.

VHF and UHF Antennas

The physical size of antenna elements becomes smaller as the frequency increases. Antennas that operate in the VHF (30-300 mc)

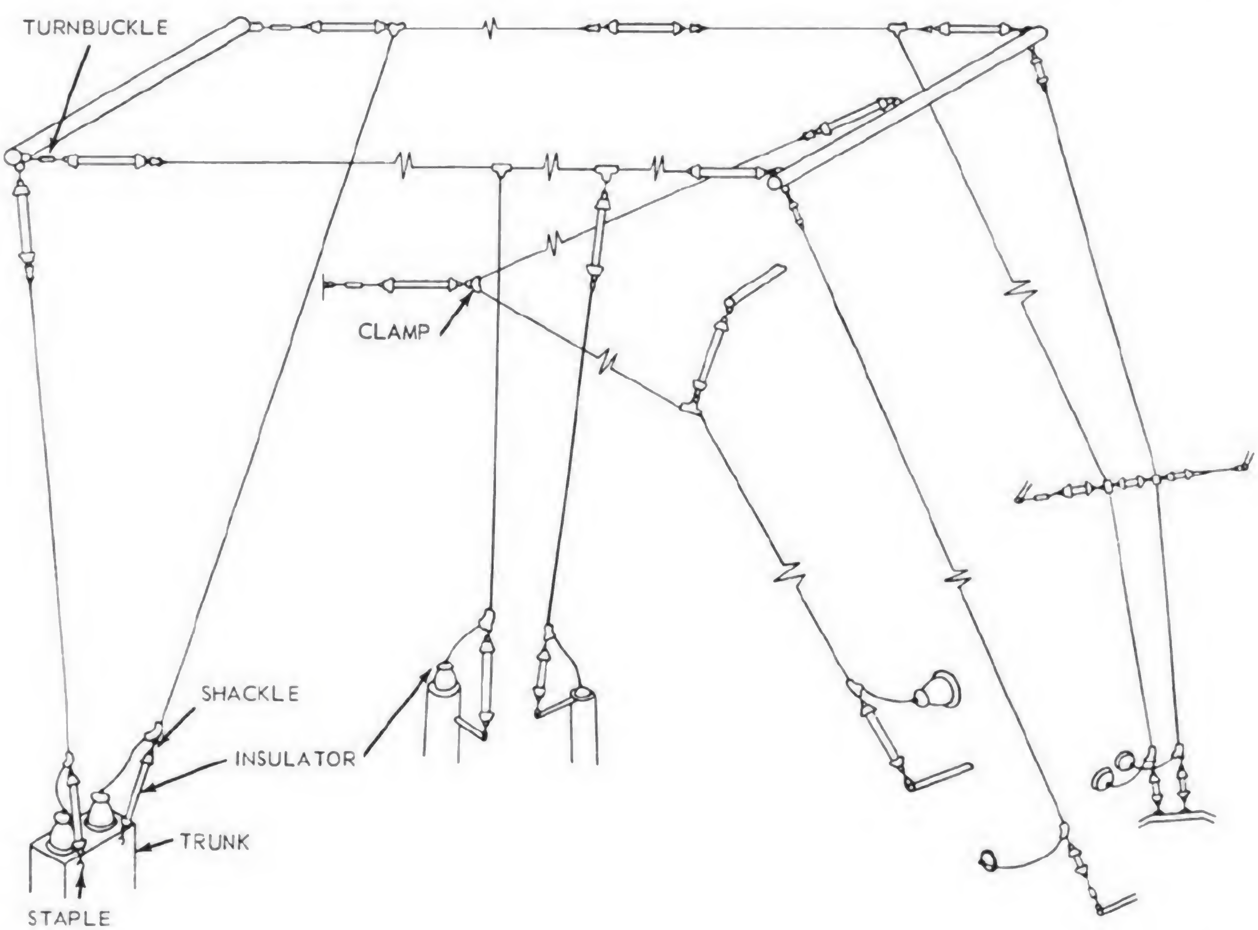


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Figure 7-13.—Typical long wire antenna installation.

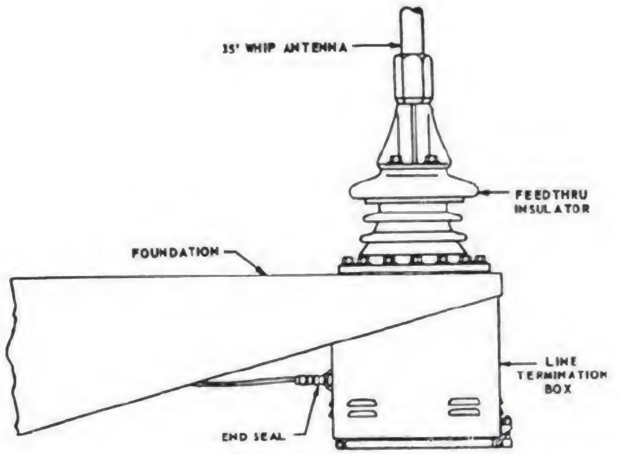

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Figure 7-14.—Method of mounting a whip antenna.

and UHF (300-3000 mc) frequency ranges are relatively small in size. Because short range communication is used in the VHF-UHF ranges, high power is not necessary. Receiver signal strength then depends upon antenna height and the distance from the transmitter.

In these frequency ranges, it is important that both the transmitting and receiving antennas have the same polarization. The Navy employs vertical polarization in the VHF-UHF ranges.

Vertical conductors such as guys, masts, rigging and cables in the vicinity of UHF antennas will cause unwanted directivity. For this reason, these antennas are mounted as high and as much in the clear as possible.

Figure 7-15 shows two types of antennas operating in the VHF-UHF frequency range. Usually, either a vertical quarter-wave stub with a ground plane (part A) or a vertical half-wave dipole (part B) is used. The ground plane prevents the metallic support mast from acting as a radiating portion of the antenna. It establishes the ground level at the base of the antenna.

Microwave Antennas

Parabolic-shaped reflectors are generally used to direct microwaves in the desired direction and in the required pattern.

Figure 7-16 illustrates that the energy from a radiating element placed at the focal point of a parabolic reflecting surface will be reflected into a narrow beam. These reflectors are usually fabricated from solid metal plate or metal screening. In many instances these reflectors are placed on rotatable mounts.

The transmission lines used at microwave frequencies are coaxial lines or waveguides, and either a front- or rear-feed system is used. In a front-feed system the waveguide or coaxial line approaches the reflector from the front and directs the spray of r-f energy into the reflector. In a rear-feed system the coaxial line or waveguide projects through the reflector from the rear, and an additional parasitic reflector is placed in front of the radiating element to direct the energy back toward the parabolic reflector.

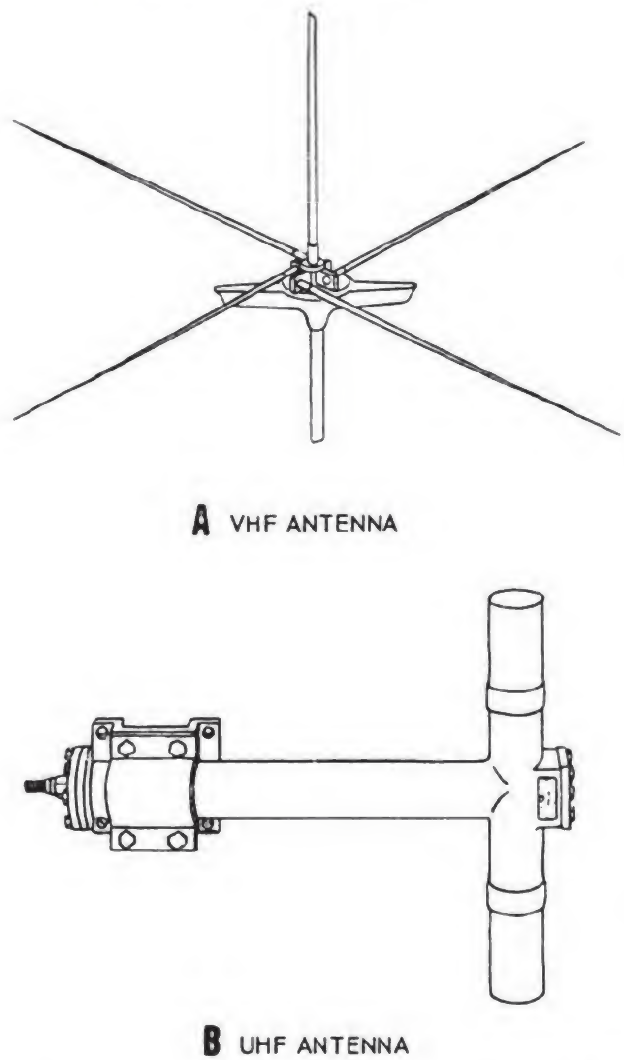

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Figure 7-15.—Types of VHF and UHF antennas.

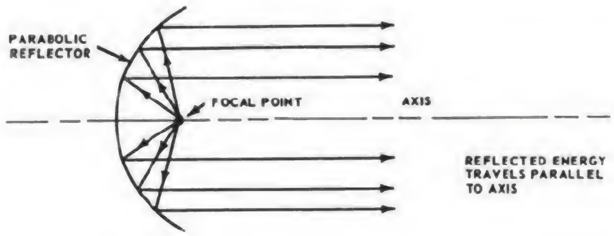

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Figure 7-16.—Principle of parabolic reflection.

INSULATION

Electrical insulation isolates current-carrying conductors from personnel, the structure, and from other conductors. For reasons of safety and efficiency the insulation chosen for a particular application must have certain desirable properties. Insulation properties include resistance, dielectric strength, dielectric loss, tensile strength, flexibility, and abrasion resistance.

Insulation RESISTANCE is the resistance to the flow of an electric current through and over the surface of insulation. This resistance should be high and is usually measured in megohms. However, the insulation may be damaged and still exhibit a high resistance to ground. Therefore, insulation resistance furnishes a useful but not a final test in determining the condition of the insulation.

The DIELECTRIC STRENGTH of insulation is a measure of the voltage that can be applied to insulation without breaking it down. It may be expressed as volts per mil of thickness. For practical purposes, it is the value obtained by dividing the breakdown voltage by the thickness of the material. When breakdown occurs, the insulation is changed abruptly from a nonconductor to a conductor.

The DIELECTRIC LOSSES in insulation result from stresses set up in the insulation when an a-c voltage is applied across it. Charges are alternately stored and released. The action is similar to that of a capacitor. The voltage causes a physical stress, and heat is produced. The heat generated in the insulation is known as dielectric loss and varies directly with the frequency. The product of the dielectric constant and the power factor is called the loss factor of the dielectric. The loss factor is a measure of the effectiveness of a dielectric to insulate high r-f voltages.

TENSILE STRENGTH is a measure of the physical force required to break a material when it is subjected to a stretch, or pull, and is expressed in pounds per square inch.

FLEXIBILITY is the ability of insulating material to withstand forming and bending without breaking. Some insulators, such as glass and porcelain, are hard and brittle and have no flexibility.

ABRASION RESISTANCE is a measure of the ability of an insulating material to withstand damage caused by handling.

The properties of electronic insulation are affected by temperature, moisture, atmospheric action, and mechanical damage.

As a rule, high temperatures cause a decrease in dielectric strength and insulation resistance. For high operating temperatures, teflon, silicone rubber, asbestos, and glass are the best insulators.

Moisture as well as high temperature lowers insulation resistance and dielectric strength of an insulating material.

SILICA GEL

Silica gel is a hard, glassy compound in the form of small crystals that can absorb moisture. It is also called a desiccant, and normally has a white or milky color. It may be mixed with a small amount of cobalt chloride or similar moisture-indicating material. With this material added, the color changes from blue to pink to red as more and more moisture is absorbed.

A typical use of silica gel is keeping coaxial lines and joints free of moisture on earlier air search radar equipments, such as the SA, SK, and SR radars.

The line is kept air-tight, and an opening allows breathing during temperature changes. A protex plug containing silica gel is placed in the opening to dry all air entering the transmission line. This method requires the replacement of the protex plug when the silica gel crystals turn pink. If the replacement of the plug is neglected, air with moisture is breathed into the coaxial line as if no protex plug were there.

MAINTENANCE PROCEDURES

AREAS OF RESPONSIBILITY

An indication of the scope of the work done by the CT M is contained in the following list (of course, not all of the jobs listed are performed by the CT M 3&2):

1. Antennas—cleaning and painting; replacement of wire antennas.
2. Bearings—replacement in small motors and generators.
3. Cabling—replacement of short lengths not critical in nature.
4. Direction finding—cleaning, routine maintenance, loop checks, and calibration.
5. Field changes—all field changes of a minor nature and those designated as being accomplished by ship's or station's force.
6. Generators—routine cleaning and replacement as required.
7. Insulators—cleaning and replacement as required.
8. Jacks (phone)—replacement and repair.
9. Keys (telegraph)—installation, replacement, adjustment, and repair.
10. Meters—minor repairs only, replacement of meters that are integral parts of equipment.
11. Oscilloscopes—repair and adjustment.
12. Receivers (all types)—all tests and repairs except alignment.
13. Transmitters (all types)—all tests, repairs, and alterations except major changes and repairs to sealed oscillator compartments.
14. Test instruments—all repairs except where special instruments or techniques are required.

MAINTENANCE CATEGORIES

OPERATIONAL MAINTENANCE consists normally of inspection, cleaning, servicing, preservation, lubrication, and adjustment, as required, and may also consist of minor parts replacement not requiring high technical skill or internal alignment.

TECHNICAL MAINTENANCE (corrective maintenance) will normally be limited to maintenance consisting of replacement of unserviceable parts, subassemblies, or assemblies and the alignment, testing, and adjustment (internal) of equipment. (This work, in general, requires skill and detailed knowledge of equipment.)

PREVENTIVE MAINTENANCE is the systematic accomplishment of items deemed necessary to reduce or eliminate failures and prolong the useful life of the equipment. (These items are more specifically defined and outlined in the instruction books furnished with each equipment. This work, in general, requires skill and a detailed knowledge of the equipment.)

REPAIR is the correction of damage incurred through long use, accident, or other causes.

MAINTENANCE BEYOND THE CAPACITY OF SHIP OR STATION FORCES is performed by tender or naval shipyards and industrial managers or by contractors or other agencies responsible to the maintenance yard.

When an electronic equipment deviates appreciably from normal operation, it will generally be noted by the operator. If the trouble cannot be corrected by operational maintenance procedures, technical maintenance (as outlined in the appropriate instruction book or technical manual) will be necessary. Technical (or corrective) maintenance procedures differ widely among the various electronic equipments, and therefore the appropriate instruction book must be used.

Besides the major units, you will be concerned also with the various accessories, such as transmission lines, antenna systems, motors, motor-generators, synchros and servomechanisms, switching systems matching devices, and others.

Electronics equipment can usually be subdivided into one or more of the following basic categories; (1) transmitter, (2) receiver, (3) amplifier, (4) indicator, or (5) recorder. The function of any transmitter (radio, radar, or sonar) is to generate the carrier frequency and then to amplify, modulate, and finally to radiate it from a suitable antenna. Every transmitter must have the required ability to stay on the assigned frequency (frequency stability), to transmit faithfully the desired intelligence (fidelity), and to produce the required output power.

The function of any receiver (radio, radar, or sonar) is to receive, amplify, and deliver the desired intelligence in a useful form. Every receiver must have the required ability to pick up weak signals (receiver sensitivity), to pick up a signal at the desired frequency while rejecting signals on adjacent frequencies (receiver selectivity), and to amplify an incoming signal and deliver it to an indicator without distortion (receiver fidelity).

The function of any amplifier is to increase the strength of the signal fed to it without adding anything to the signal or removing anything from it.

The function of any type of indicator is to present information in the desired manner, without distortion.

The function of any recorder is to make a permanent and true record of a voice, signal, or any digital information on tape, wire, or disk for subsequent playback and use.

PREVENTIVE MAINTENANCE PROCEDURES

In this portion of the chapter some of the more common preventive maintenance procedures are discussed briefly. It is obvious that the way the operator or the technician goes about his preventive maintenance duties depends upon the type of equipment (or equipments) to which he is assigned. If the Maintenance Check-Off Book is available, the task is made easier. In any case, the steps to be followed in performing preventive maintenance are spelled out in detail in the equipment instruction book. Generally, one section (Section 6) of the instruction book is devoted entirely to preventive maintenance. However, in the new specifications, preventive maintenance will be included in the operator's volume or in the POMSEE books.

Certain items like cleaning and lubricating electronic equipment, maintaining air filters, caring for motors and motor-generators, and testing electron tubes and crystal diodes are sufficiently general to be treated under separate headings. However, preventive maintenance, as applied to specific equipments, must conform to the specific routine spelled out in the Maintenance Check-off Book or the equipment instruction book. To illustrate the methods commonly used in maintaining the various types of electronic equipments, a brief summary of the preventive maintenance procedure for certain typical equipments is included. For the detailed procedure, the equipment instruction book must be consulted in each case.

Preventive maintenance includes daily checks on the operating controls to note binding, excessive play, or other defects. Meter readings should be checked daily to determine if they are normal (the exact procedures are outlined in the appropriate Maintenance Check-Off Book). Equipments should also be checked daily for loose knobs, burned out pilot lights, loose cable couplings or bonding straps, missing spare fuses, and broken meter glasses.

Also, external surfaces should be dusted periodically. Interiors of equipments should be cleaned carefully at weekly intervals with a soft brush and, if available, a vacuum cleaner.

Periodic cleaning of the interior of radio transmitters or other equipments employing high voltage is particularly important. Potentials in excess of 3000 volts are often present in these equipments, and dust on insulators or other high-voltage components forms a convenient path for arc-overs and consequent damage. In addition, a mixture of dust and lubricant forms an excellent abrasive, which can do considerable damage to moving parts.

The POMSEE Program

The Bureau of Ships is supplementing existing instruction books or technical manuals with two separate publications which together make up the POMSEE program. The expression, POMSEE, means "Performance, Operational, and Maintenance Standards for Electronic Equipment." The POMSEE publications are described as follows:

1. Performance Standards Sheets provide the operational performance data and basic technical measurements indicative of the minimum acceptable level of performance for electronic equipment. A binder, titled "Binder for Electronic Equipment Performance Standard Sheets (NavShips 93000)," for incorporating all sheets required under one cover, has been distributed.

2. Maintenance Standards Books provide standard methods for determining measurements affecting the performance of a specific equipment, space to record such measurements, and a preventive maintenance schedule for the equipment. The Maintenance Standards Book includes Part I, Test Procedures and Maintenance References (formerly Performance Standards Book, and referred to as such in this training course) and Part II, Preventive Maintenance Check-Off (formerly Maintenance Check-Off Book, and referred to as such in this training course).

According to Bureau of Ships Instruction 9670.86A, all holders of POMSEE publications are required to change the title of all "Performance Standards Books" to "Maintenance Standards Books, Part I, Test Procedures and Maintenance References" and to change the title of all "Maintenance Check-Off Books" to "Maintenance Standards Book, Part II, Preventive Maintenance Check-Off."

"Performance Standard Book". (Maintenance Standards Book, Part I, Test Procedures and Maintenance References) provides an itemized step-by-step procedure, which enables the engineer or other person making the standard tests to set down critical or significant operating values (dial readings, etc.) representative of optimum operating conditions. Upper and lower limits or tolerances for dial readings, voltages, or currents are given so that an indication is readily available if performance is below the allowable limits. No attempt is made in the Performance Standards Book to show how to locate the trouble; however, a comparison with established critical circuit readings will help the technician to isolate the trouble.

Reference to the instruction book for the particular equipment is still required for troubleshooting or corrective maintenance.

The Maintenance Check-Off Book (Maintenance Standards Book, Part II, Preventive Maintenance Check-Off) requires that standard tests be performed at regular intervals on circuits and components and specifies what and when other routine maintenance, such as lubrication, is to be accomplished. By the proper use of this book, routine checks and routine preventive maintenance may be accomplished in a systematic manner.

In general, the same steps required for determining Performance Standards must be repeated later by the ship's or station's force in making routine checks for entry in the Maintenance Check-Off Books. The daily and some of the weekly tests prescribed should be done by operators, not technicians, so that the technicians can concentrate on corrective maintenance.

Cleaning Electronic Equipment

The following information was obtained from Chapter 9670 of the Bureau of Ships Technical Manual.

1. All electronic equipment must be cleaned to assure good performance and not for appearance only.
2. Steel wool or emery in any form must not be used on or near electronic equipment.
3. Sandpaper and files will be used only with competent advice or not at all.
4. A vacuum cleaner with NONMETALLIC hose and adequate dust receiver should be used wherever practicable.
5. The use of solvents is to be resorted to only where absolutely necessary and where the proper safety precautions are taken (see Chapter 9150, Section 8 of BuShips Technical Manual).

Alcohol or other flammable solvents must not be used on energized equipment or on equipment near other electronic equipment from which a spark is possible. They are to be exposed in the smallest possible quantity and may be used only in well-ventilated compartments. Except in locations wholly in the open, alcohol will be limited in quantity to one pint.

For additional safety precautions that the CT M must observe in cleaning electronic equipment, see United States Navy Safety Precautions, OpNav 34P1.

Lubricating Electronic Equipment

In electronic gear, lubrication is as important as it is anywhere else, and the carrying out of the lubrication procedure is no more complicated than in other equipments. There are actually only a few types of parts that have to be lubricated. They are summarized in a general way as follows:

1. Drive motors and motor-generator sets run at high speeds and if not lubricated properly at regular intervals will quickly deteriorate and fail. Determine where the motor-generators (as well as the drive motor) are located so that they will not be overlooked during routine lubrication.
2. A radar antenna is rather slow-moving, but a great deal of trouble and expense has resulted from a lack of proper lubrication. In one instance the failure to use thirty cents worth of grease resulted in a $30,000 repair bill. Several factors combine to cause antenna trouble. First the antenna is a long way up in the air, and it is a nuisance to climb up the mast or tower to lubricate it. Second, if the antenna is part of a shipboard installation, the constant pitching and rolling of the ship make lubrication a hazardous job as well as exerting great pressures and strain on the moving parts of the antenna causing rapid wear if not lubricated regularly. Third, the antenna pedestal is constantly exposed to the action of air and water, often salt air and salt water, which attacks the lubricant and tends to make it less effective.

If the antenna is neglected and the pedestal freezes, the drive motor will burn up, and the

radar will be out of commission. This condition involves lifting the antenna off with a crane and results in an expensive repair job. This waste of money and time, and the possible placing of the ship in jeopardy, can be prevented if the correct lubrication procedure (as outlined in the instruction book, the lubrication charts, or POMSEE books) is followed.

There are three common methods of lubricating electronic equipment.

The first is the use of the oil can. A drop of oil from the spout of the can into the oil hole on the machinery is all that is necessary. However, there are many types of oil and you must be sure that you are using the correct one. In many cases, the mixing of dissimilar oils will form a gummy substance that has little or no lubrication properties. The result may be a frozen bearing.

The second is the use of a grease gun on a pressure-type fitting. The main thing to remember is that the fitting must be clear of dirt or paint obstructions, otherwise the grease cannot enter. Even if the grease should be forced in, dirt will be taken along and eventually the bearing will be damaged. Grease fittings should always be kept as clean as bright work; and the hole should be cleaned out with a pin before the grease gun is applied.

The third is the use of the grease cup. Grease cups are generally found on the heavier motors and motor-generators, and must be used properly if damage to the machinery is to be prevented. Information on the use of grease cups is included in the section on the care of motors and motor-generators.

For certain types of electronic equipment, special lubrication charts are provided. For example, a set of twelve plastic lubrication charts (NavShips 250-970-40) are provided for the personnel who lubricate the antenna of Radar Set AN/SPS-8. Pictures and instructions are given to ensure adequate lubrication instructions.

Care of Motors and Motor-Generators

The following information on the care of motors and generators (or motor-generators) is condensed largely from Chapter 9600 of the Bureau of Ships Technical Manual. The essential points to remember are: (1) keep the insulation clean and dry and of high resistance, (2) keep the electrical connections tight, and (3) keep the machines in good mechanical condition by proper cleaning, lubrication, and replacement of defective parts.

The CT M is expected to be able to inspect and clean commutators and collector ring (slip ring) assemblies and inspect and replace brushes on motors and motor-generators that are used with or are a part of electronic equipment. It is therefore important that he follow the approved procedures.

The four acceptable methods of cleaning motors and generators are wiping, use of suction, use of compressed air, and use of a solvent.

LUBRICATING.—The CT M should be familiar with and be able to distinguish between grease-lubricated and permanently lubricated ball bearings.

The grease-lubricated type requires periodic lubrication with grease. The permanently lubricated type contains two seals, has been lubricated by the manufacturer, and requires no additional lubrication throughout its life. Equipment furnished with these bearings can be recognized by the absence of grease fittings or provision for attaching grease fittings. When permanently lubricated bearings become inoperative they should be replaced with new bearings of the same type.

Cleanliness is of prime importance in avoiding ball bearing failure. Because of the extremely high pressures and close fit between balls and races, even minute particles of dust may cause bearing failure. Dirt may be introduced into the bearing housing by careless handling, or by inclusion with the lubricant, or it may work its way into the housing along the shaft.

Extreme care must be exercised in the handling of bearings, grease fittings, housing parts, and tools used in maintaining the bearings to ensure the exclusion of all foreign matter, particularly when reassembling grease fittings, etc.

Improper greasing procedures are a frequent cause of trouble in rotating electrical machinery provided with grease-lubricated ball bearings. The trouble is generally caused by an excessive quantity of grease being forced into the bearing housing. When grease is forced through the bearing seals and into the windings (or onto the commutator), deterioration of the insulation is a likely result. Excessive grease in the bearing housing itself results in churning, increased temperatures, rapid deterioration

of the grease, and ultimate destruction of the bearing.

The stock numbers of grease to be used for lubricating ball bearings that operate in two broad temperature ranges are given in Chapter 9600, Article 9600-287 of the Bureau of Ships Technical Manual. Machines that require the special high-temperature silicone grease have a plate with the words, USE HIGH TEMPERATURE GREASE, attached near the grease fitting.

Motors and generators provided with bearings that should be lubricated with grease are normally delivered with the grease cups removed from the bearing housings and replaced with pipe plugs. The grease cups are delivered with the onboard repair parts or special tools. It is recommended that grease cups be attached to electric motors and generators only when the bearings are being greased. When the grease cup is removed from the bearing housing after a bearing has been greased, the hole that remains should be plugged with a suitable pipe plug. When this procedure is used, the grease cups should remain in the custody of responsible maintenance personnel.

Care should be taken to make sure that a grease cup is clean before it is used to add grease to a bearing and that the pipe plug used to replace the grease cup after greasing is also clean.

To avoid the difficulties caused by an excessive amount of grease, grease should be added only when necessary; and, when grease is added, it should be done as follows:

1. Wipe outside of grease fitting and drain (relief) plug free of all dirt.
2. Remove bearing drain plug, and make sure that passage is open by probing with a clean screwdriver or other suitable instrument.
3. Remove pipe plug at top of grease pipe. Select the proper grease cup and clean it (top and bottom parts) thoroughly. Install the bottom portion of the grease cup on the grease pipe.
4. Fill the bottom part (receptacle) of the grease cup with clean grease.
5. Put into the top part (the part that is to be screwed down) of the grease cup no more grease than will half fill it.
6. Screw the top part of the grease cup down as far as it will go. The purpose of screwing the grease cup down is to protect the machine from being overgreased because of accidental or unauthorized turning of the top part of the grease cup.
7. Run the machine and let the grease run out of the drain hole until drainage stops (normally about 30 minutes). Remove grease cup and replace the pipe plug and the drain plug.
8. Do not use a grease gun to lubricate bearings unless there are no other means available. If a grease gun must be used, the drain plug must be removed while greasing is being done and extreme care must be used to avoid inserting too much grease.

CARE OF BRUSHES.—The correct grade of brushes and correct brush adjustment are necessary to avoid commutation trouble. For good commutation:

1. Use the grade of brushes recommended by the manufacturer.
2. The brush shunts or "pigtails" should be securely connected to the brushes and the brush holder.
3. Brushes should move freely (for example, 1/32 inch), but should not be loose enough to vibrate in the holders.
4. Brushes that are half worn, or that have chipped corners or edges, should be replaced after all dirt is cleaned from the brush holders.
5. The spring tension on the brushes should be maintained according to the manufacturer's instructions (see BuShips Technical Manual, section 9600-293, for details).
6. All brush holders should be the same distance from the commutator-not more than one eighth of an inch, or less than one sixteenth of an inch.
7. The toes (forward edge in the direction of rotation) of all brushes on each brush stud should line up with each other and with the edge of one commutator segment.
8. The brushes should be evenly spaced around the commutator.
9. Brushes should be staggered in pairs (see Article 9600-293 in BuShips Technical Manual) to prevent grooving of the commutator.
10. The brush surface in contact with the commutator should be an accurate fit.

When new brushes are installed, or old brushes do not fit, they should be fitted and seated. For this purpose, sandpaper and/or a

brush seater should be used. Sandpaper is probably more familiar to everyone, but the use of a brush seater has certain advantages. (Never use emery paper or any other kind of paper or cloth containing a metallic abrasive.)

When using sandpaper to fit brushes, disconnect all power and make sure the machine cannot be started while the work is being done. Lift the brushes to be sanded and insert a strip of fine sandpaper (No. 1) sand side up, between the brushes and the commutator. With the sandpaper held tightly against the commutator surface (to conform to the curvature), and the brushes held down by normal spring pressure, the sandpaper is pulled in the direction of normal rotation of the machine (see fig. 7-17). When the sandpaper is reinserted for another pull, the brushes must be lifted. This operation is repeated until the fit of the brush is accurate. Always finish with a finer grade (No. 0) sandpaper. Use a vacuum to remove the dust during the sanding operation; afterwards, the commutator and windings must be thoroughly cleaned to remove all carbon dust.

The brush seater consists of a mildly abrasive material loosely bonded and formed in the shape of a stick about five inches in length. The brush seater is applied to the commutator while the machine is running, and therefore every precaution must be taken to prevent injury to the person applying it. The brush

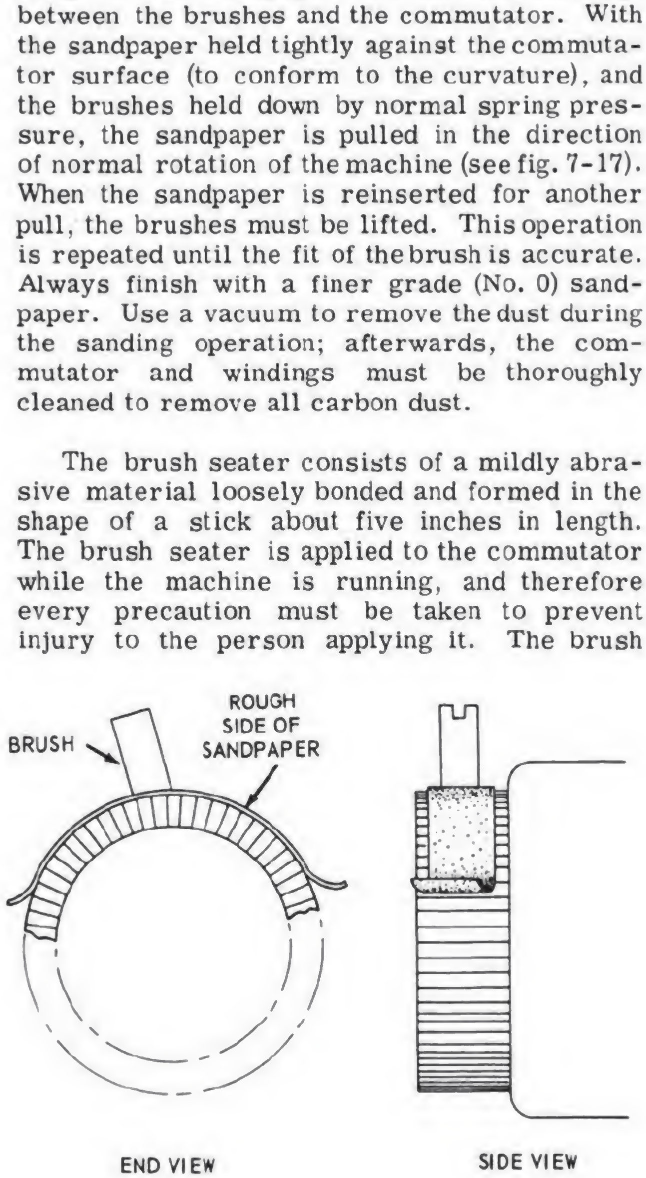

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Figure 7-17.—Method of sanding burshes.

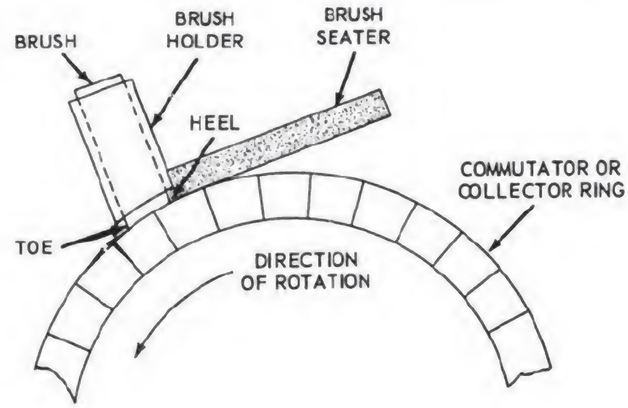

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Figure 7-18.—Using the brush seater.

seater is applied lightly, for a second or two, exactly at the heel of each brush (fig. 7-18). If the seater is placed even one-fourth inch away from the heel of the brush, only a small part of the abrasive will pass under the brush. Pressure is applied to the brush by setting the brush spring tension at maximum (during the seating operation) or by pressing a stick of insulating material against the brush. Dust is removed during the operation, and the machine is thoroughly cleaned afterwards, the same way as when sandpaper is used.

COMMUTATORS AND COLLECTOR RINGS. – In a properly operating machine, the commutator will develop (within about two weeks of use) a uniform, glazed, dark brown polish where the brushes ride on it. A nonuniform color or surface or a bluish color indicates improper commutation conditions. If the commutator retains a smooth, uniform finish of the proper color and shows no evidence of poor commutation, it may be cleaned with a canvas wiper, as described in the following paragraph. If however, the commutator cannot be sufficiently cleaned with the canvas wiper, or if the surface is slightly rough, a fine grade of sandpaper may be needed. Periodic inspections and proper cleaning practices will keep commutator and collector-ring troubles at a minimum.

One of the most effective ways of cleaning commutators or collector rings is to apply a canvas wiper while the machine is running. The wiper can be made by wrapping several layers

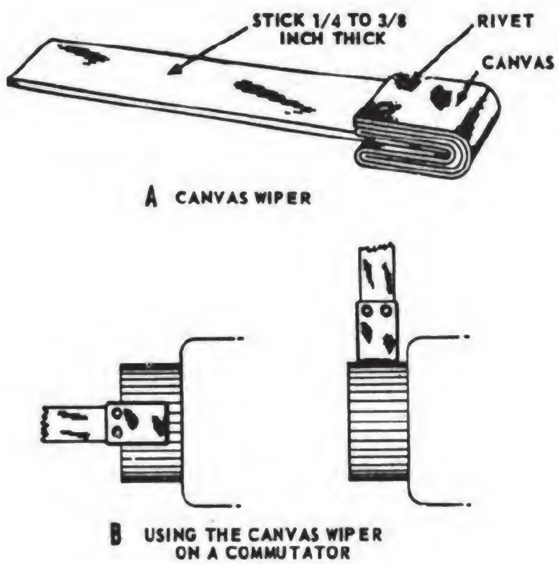

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Figure 7-19.—(A) Canvas Wiper. (B) Using the canvas wiper on a commutator.

of closely woven canvas over the end of a strong, pliable wood strip and securing the canvas with rivets, as shown in figure 7-19A. The strip should be long enough so that the user can hold it securely in both hands, about one-fourth inch to three-eighths inch thick, and of a width appropriate to the size of the machine on which it will be used. Linen tape should be wrapped around the canvas wiper over the rivets to prevent all possibility of their coming in contact with the commutator. The canvas wiper is applied to the commutator in either of the ways illustrated in figure 7-19B. When the outer layer of canvas becomes worn or dirty, it is cut off to expose the next layer.

When the machine is secured, use a toothbrush to clean out the commutator slots, and wipe the commutator and adjacent parts with clean canvas or cheesecloth. Take care not to leave threads lodged between the commutator bars or on the brushes. Do not use cottom waste or any cloth that leaves lint.

Do not use solvents for routine cleaning of commutators, and do not use any lubricant on the commutator.

If the commutator is only slightly blackened, scratched, or dirty, but not out of true (flat, grooved, or eccentric), a fine grade of sandpaper (No. 00) may be used. Sandpapering is also used to reduce high mica, or to finish a commutator that has been ground or turned. The machine is run under a light load at approximately rated speed. The sandpaper is attached to a wooden block that has a face shaped to the same curvature as the commutator. Move the sandpaper very slowly back and forth in a direction parallel to the axis of the machine. Rapid motion of the sandpaper will cause diagonal scratches. Do not use coarse sandpaper because this will make deep scratches. Do not use emery paper, emery cloth, or emery stone on a commutator as these materials contain carbon, which will become embedded in the commutator slots and short-circuit the armature coils.

Maintaining Air Filters

The maintenance of air filters is EXCEEDINGLY important for the proper operation of electronic equipment. The lack of proper servicing (cleaning or replacing) of air filters will cause an enormous amount of trouble. For some reason (perhaps they are difficult to locate or their importance is not fully recognized) it appears that air filters are often neglected or disregarded until excessive heating causes a breakdown of the equipment.

Equipments that use a great deal of power and/or have high ambient temperature must be cooled. Air cooling is commonly employed, and this means moving a large volume of air over the hot portions of the equipment. The air is filtered to keep dust and other foreign particles out of the equipment. If the filters are efficient, they will remove most of this foreign material from the air that passes through them. This foreign material will tend to clog the filter and prevent the air from moving through. The result is that the equipment gets too hot and may be ruined. Air filters must be serviced often.

An analysis of the failures of parts in electronic equipment indicates that the majority of failures can be traced to excessive heat caused by dirty air filters. This fact cannot be overemphasized; and on the basis of this alone, it would appear that the technician can reduce his workload substantially by ensuring that air filters are properly serviced.

Maintaining Antennas and Transmission Lines

Specific instructions for maintaining VHF/UHF and microwave antennas are given in the instruction book for a particular equipment or a particular antenna. Good practical information on testing antenna systems is included in Chapter 4 (Testing Antenna Systems) of Shipboard Antenna Details, NavShips 900,121A. Equally helpful is the information on transmission lines contained in Installation and Maintenance of Transmission Lines, Waveguides, and Fittings, NavShips 900,081. Another useful publication is Armed Services Index of R-F Transmission Lines and Fittings, NavShips 900,102B.

This portion of the chapter treats in a general way the use of meggers in testing antenna systems and the cleaning of antenna and transmission line insulators. However, before the subject of testing antenna systems is treated it is perhaps best to review what is said about the ohmmeter and the megger in Basic Electricity, NavPers 10086.

Basically, an ohmmeter (or the ohmmeter section of a multimeter) is used to determine if a circuit is open, shorted, or grounded; it is likewise used to determine the resistance of a circuit or component. It is simple to use. The test leads are connected to the instrument, and the range switch and the meter adjustments are made. The probes are then placed across the circuit or component to be tested. If no reading is obtained (infinite resistance), the circuit is open (or the resistance is so high that the meter will not give an indication); if a reading is obtained, the circuit is not open. If no resistance is indicated, the circuit or component is short-circuited. If the ohmmeter indicates essentially no resistance between a point in a circuit and ground, that point is grounded. The value of the resistance of a circuit or component is indicated on the meter dial.

In general, ohmmeters are used for low or medium values of resistance; meggers and insulation test sets are used for high values of resistance (perhaps hundreds of megohms).

USE OF INSULATION TESTERS.—The theory of operation of the megger is discussed in Basic Electricity, NavPers 10086-A. Essentially, it consists of a d-c generator supplying a 2-branch circuit, which contains an indicating meter calibrated to read in megohms the unknown resistance inserted in one of the branches.

The megger is used to check the insulation resistance of antennas, transmission lines, cables, generators, motors, transformers, and so forth. Occasional checks over a period of time with a megger will show the condition of insulating material used on antennas and transmission lines and in this manner indicate likely faults. It is also widely used to detect, or track down, insulation faults after they have occurred.

Another type of insulation test set (closely related to the megger) employing an a-c generator, rectifier, and an ohmmeter circuit with a conventional d-c milliameter (Insulation Test Set AN/PSM-2A) is illustrated in figure 7-20. It is designed to measure insulation resistance from 0 to 1000 megohms. The testing voltage is 500 volts d-c.

The meter pointer should read infinite resistance when there are no external connections to the output binding posts, L, and GND. If the pointer does not stand over the infinity mark, it is necessary to adjust the meter adjustment screw until the pointer stands over the infinity mark. When the meter terminals are short-circuited and the crank is turned at normal operating speed (indicator buttons glowing steadily), the meter pointer should be over the zero mark.

The operation of the insulation test set is relatively simple.

1. Be sure that the apparatus, line, or circuit to be tested is disconnected from its power supply in accordance with safety instructions. Ground the apparatus, line, or circuit to be tested to discharge any capacitors connected to it.

2. Connect the spade-type terminal lug of the black lead to the GND binding post of the test set.

3. Attach the alligator clip of the black test lead to the side of the circuit (under test) nearest ground potential.

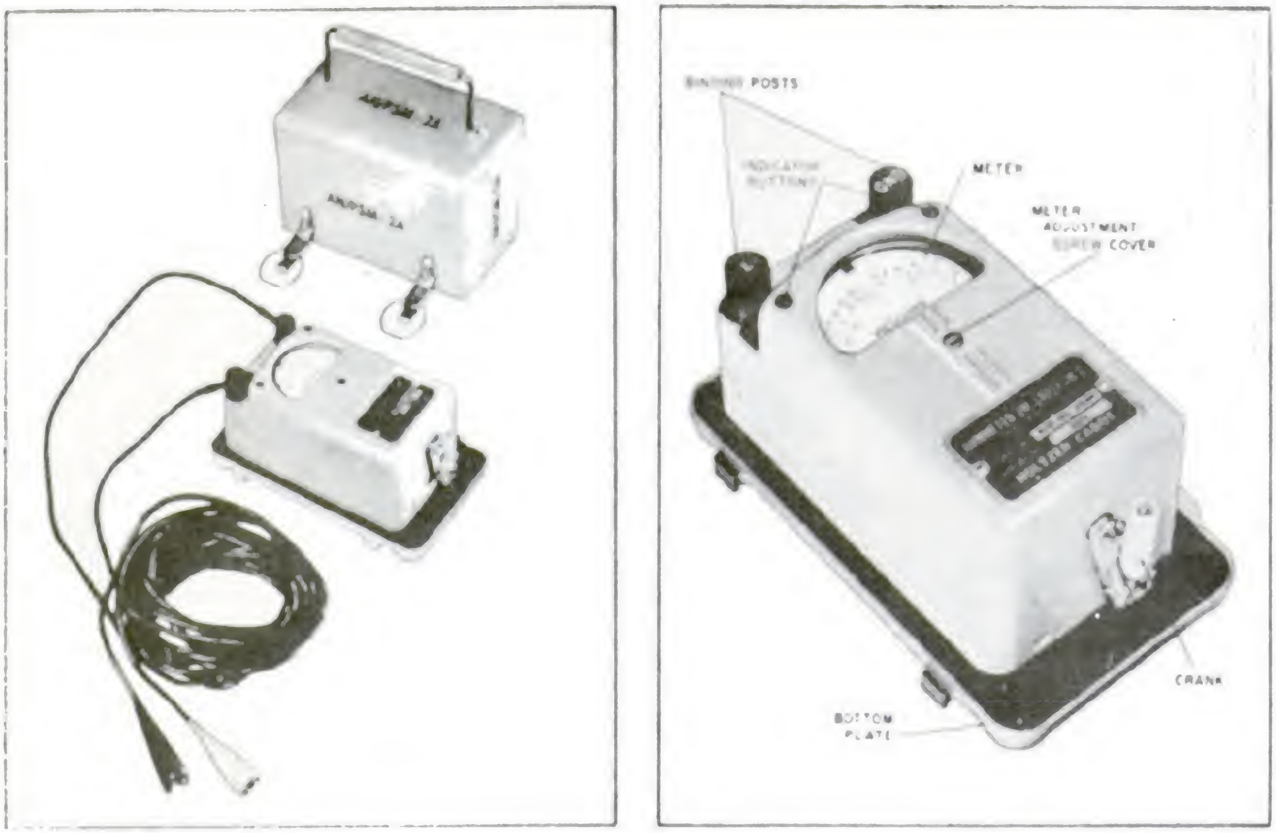

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Figure 7-20.—Insulation Test Set AN/PSM-2A.

4. Connect the spade-type terminal lug of the red lead to the L binding post of the test set.

5. Attach the alligator clip of the red test lead to the conductor to be tested.

6. Turn the crank in either direction at the minimum speed required to provide steady illumination of the indicator buttoms.

7. Read the megohms of resistance offered by the material being tested. If the resistance is more than 1000 megohms at 500 volts d-c, the meter will remain at rest over the infinity mark ( ), indicating that the resistance of the insulation being tested is beyond the range of the meter.

Measuring the insulation resistance of lines and antennas is a very important and effective means of determining the condition of the antenna and its transmission line. Readings taken in these tests should be 100 megohms or greater, although lower readings will be registered on wet or humid days. Ofcourse, megger tests are more meaningful if made during good weather. Some antennas have a d-c short circuit and therefore the insulation resistance cannot be measured directly; among those that are short-circuited with respect to direct current are the AT-150/SRC, the AS-390/SRC, the NT-66015, and the NT-66016.

Before performing any tests, the megger should be checked to determine if it is in good working order, as explained previously. Make good, positive, clean connections to antenna and ground otherwise the contact resistance will be an appreciable part of the total megger reading.

For most antenna installations the test procedure is as follows:

1. Disconnect the transmission line at the equipment and test the line at this point.

(NOTE: Do not connect the megger to the equipment at any time.)

2. If the reading registers below 100 megohms, disconnect the transmission line at the antenna and test individually both the transmission line and the antenna at this point. This will indicate that the trouble lies either in the transmission line or the antenna or both.

3. If the trouble (low-resistance indication) is shown to be in the transmission line, disconnect the line at the various coaxial connectors and test the individual sections of the line to further localize the trouble.

4. If the trouble (low-resistance indication) is shown to be in the antenna, the antenna will have to be repaired. (However, it should be recalled that certain antennas normally contain a d-c short circuit. The resistance of these antennas should be approximately zero ohms, as indicated on a low-reading ohmmeter.)

These tests are made at prescribed intervals, and the readings are recorded on the proper forms (the Maintenance Check-Off Books, Resistance Test Record Card, etc.).

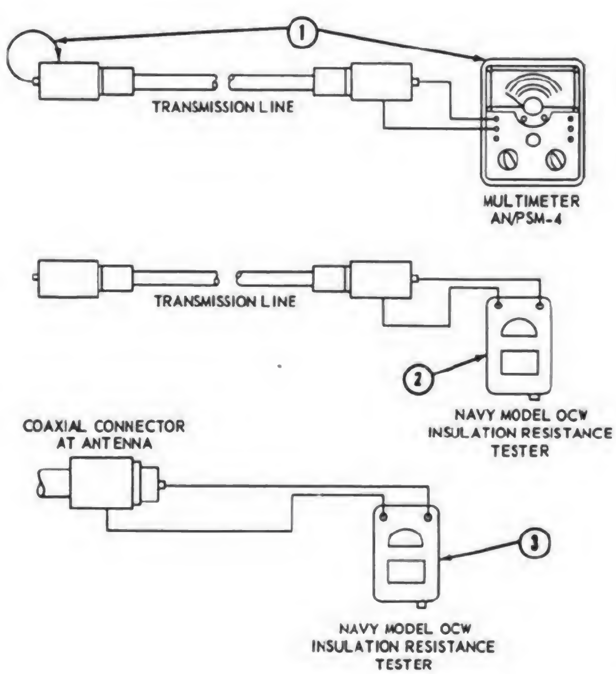

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Figure 7-21.—Meter connections for making antenna and transmission-line measurenents (receiver).

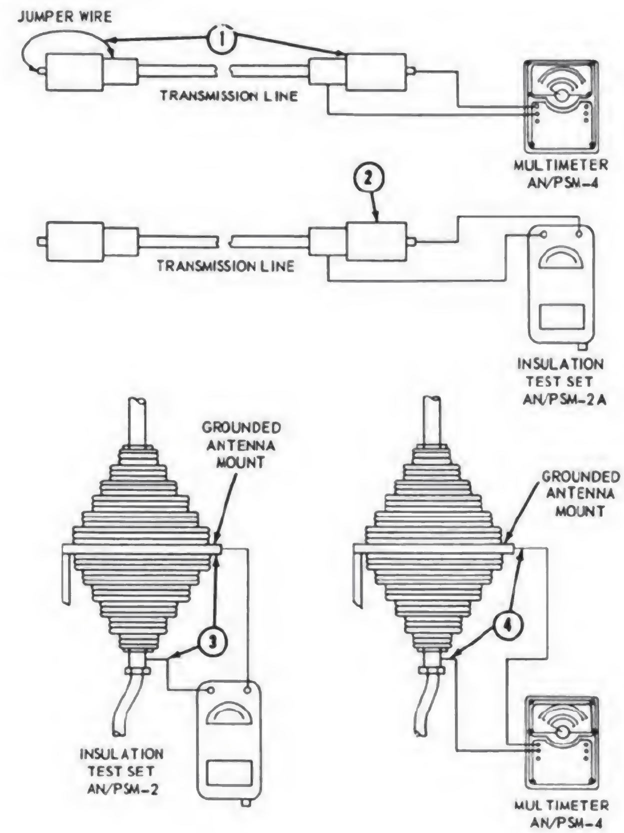

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Figure 7-22.—Meter connections for making antenna and transmission-line measurements (transmitter).

Continuity checks are also made with the megger or a multimeter. In performing these tests, the transmission line is disconnected at both ends. At one end, the inner conductor is shorted to the outer shield. At the other end, the resistance between the inner conductor and the outer conductor is measured.

The meter connections for making antenna and transmission line measurements are shown in figure 7-21 and figure 7-22.

CLEANING INSULATORS.—Leakage current over the surface of an insulator is usually due to moisture and impurities on the surface such as salt spray, soot, or dust.

All standoff insulators, end seals of transmission lines, and waveguide windows should be cleaned at least once a month, and more often if conditions warrant.

The smaller the insulator, end seal, or waveguide window, the more important is this maintenance procedure. The cleaning must be thorough with nothing left to chance.

Paint, varnish, shellac, or grease must not be applied to any portion of ceramic or phenolic insulating materials forming a part of the antenna system.

Testing Electron Tubes

The leading cause of failure or poor operation of electronic equipment (transmitters as well as receivers) is the electron tube. If all tube failures could be eliminated, the maintenance load would be reduced considerably. Tubes do not always collapse completely. Their performance may gradually deteriorate but not to the extent that it will be apparent in a tube checker. One reason for the failure of the average tube checker to give a full indication of the capabilities of a tube is the 60-cycle sine wave that is applied at frequencies varying from a few cycles to several billion cycles per second. The usual tube tester cannot determine accurately the ability of a tube to act as an oscillator or as an ultra high frequency amplifier.

Because of the importance of the method of using the tube checker, the Bureau of Ships has issued an instruction (BuShips Inst. 9870.89) establishing the general policy for testing electron tubes. Additional information is included in the June 1956 issue of the Bureau of Ships Journal. A portion of BuShips Inst. 9670.89 is contained in EIB No. 455, and is repeated as follows:

The practice of wholesale removal and test of electron tubes on a periodic basis is to be discontinued immediately. Action is being taken to revise instruction books that specify such routine. If routine test of an electron tube in a designated application is necessary, the instruction book will specify an exception to the rule.

The following maintenance routine is strongly recommended:

1. When a performance deficiency is detected, make an all-out attempt to isolate the specific cause.
2. When the trouble has been localized and a tube is suspected, remove and test that tube. If found good, replace in the same socket. Interchange of tubes between sockets should be avoided.
3. If repair by tube substitution is necessary as a last resort, test the new tube (within the capability of the tube tester) before placing it in service.
4. If a new tube tests good but will not work in a particular socket, make a note of this fact and save the tube for use in another application where it will work. The Bureau of Ships is particularly interested in receiving information on cases where extensive selection of tubes for a particular socket is necessary for proper operation. Failure Report Forms (DD787) and Performance and Operating Reports (NavShips 3878) are convenient ways to do this.

Maintaining Earphones and Microphones

The best way to maintain earphones and microphones is to ensure that they are handled properly. Proper handling includes, for example, hanging up earphones by the straps, not by the cord; removing a plug from a jack by grasping the plug, not the cord; avoiding kinks or other strains in the cord; avoiding rough handling of microphones and earphones, and avoiding exposure to moisture. Heat lamps may be used to protect or to dry out carbon microphones.

Repair consists largely of replacing or repairing plugs, jacks, and cords. In any case, do not place defective equipment with the ready spares. It should be repaired first.

Radio Transmitters

The correct preventive maintenance procedure for any type of transmitter is included in the instruction book that accompanies the equipment. It is the purpose of this portion of the chapter to list some of the general procedures used in maintaining any transmitter.

GENERAL MAINTENANCE.—The CT M should make every effort to become familiar with the equipment in order that he may be able to recognize and anticipate avoidable defects. Table 7-2 will be of assistance in making these observations.

The radiofrequency amplifier meter readings (power amplifier current, intermediate power amplifier current, and voltmeter) should be taken under the same conditions and with the same antenna or dummy load. Weekly readings are to be made and compared with those of

Table 7-2.—Initial Checks.

Item	Check
1. Primary Power . .	The ship power supply must be available at all times.
2. Control Equipment.	Radiophones, teletype, facsimile, hand keys and other control equipment must be in good working order and connected properly.
3. Insulators	Antenna and line insulators must be kept clean and free of unwanted grounds.
4. Cables	All internal and external cables must be firmly and properly connected.
5. Dirt and Moisture .	Leakage paths are often provided by dirt and moisture, resulting in arc-overs and loss of efficiency.
6. Loose Parts	In operation, some mountings or fittings may work loose or become damaged. Correct this condition as quickly as possible.
7. Visual Check	Check for broken, damaged, or loose hardware; meters; knobs; dials; or lamps. Replace damaged parts without delay.

the previous week so as to check the various conditions existing. It should be borne in mind that production-line tubes will vary considerably in their current output readings. However, a definite trend or fluctuation in the readings is to be interpreted as an indication of trouble. By charting these fluctuations, a reliable record of tube performance is available for ready reference and indication of trouble may be avoided by changing tubes before a critical stage is reached.

Complete instructions for taking and recording the meter readings are given in the Maintenance Check-Off Book for the equipment.

Some general maintenance procedures may be listed as follows:

1. Check for unusual odors, such as that of hot plotting compound, which might indicate an overloaded transformer; burning paint, due to overheated resistors; and burning rubber, due to excessive current through a rubber-covered conductor.

2. Use an air hose to remove dust, dirt, and foreign particles. Extreme care must be exercised when the air hose is used around delicate parts such as tuning capacitors. As a precautionary measure, the air line should be purged of moisture by directing the nozzle toward the floor and releasing the air in the line before directing it toward the equipment.

3. Avoid, if possible, disturbing the layout of the wiring. If wiring must be removed, be sure to return it to its original position after the cleaning procedure to prevent oscillation, feed-back, and other circuit disturbances. Check all sockets, and remove any dirt or corrosion with solvent or with fine sandpaper or crocus cloth.

4. After cleaning, inspect the equipment for faulty or damaged parts. Some of these parts include tube sockets and contacts, springs, gears, tuning capacitors, potentiometers, bandswitches, insulators, terminal strips, jacks, plugs, and hinges. Check for and replace or secure loose or damaged hardware.

5. The operating controls should be given a careful visual inspection and then checked for correct operation and setting. Turn each control slowly to its maximum clockwise limit, then to its maximum counterclockwise limit. Binding or scraping should be noted and corrective measures taken.

6. In gear assemblies and in tuning mechanisms back-lash must be held to a minimum. Hence, trouble of this sort should be noted and corrected or reported as soon as possible.

7. Replace damaged parts, such as shorted or leaky capacitors or burned out resistors. However, before actual replacement of the damaged part, the circuit should be carefully inspected to find the cause of the trouble. Only in extreme emergencies should replacement be made without a checkup.

8. It is important to remove dirt or corrosion on the prongs of plug-in parts, such as tubes, jacks, and plugs, to avoid a high-resistance connection between the prong and its socket. Use crocus cloth or fine sandpaper.

9. Cables and cords and their jacks and plugs must be checked for damage to their inserts and insulation. Look for opens, shorts, and intermittent contacts. The latter may often be found by wiggling the plugs in their sockets. If damage is found, or if trouble is suspected, use an ohmmeter to check for continuity in the cords and cables.

LUBRICATION.—The lubrication procedure is spelled out in the instruction book. However, the following information is generally applicable to radio transmitters.

When dispensing a lubricant, wipe all dirt, dust, or moisture from around the opening of the container. The containers must be kept closed when not in use to prevent moisture condensation on the surface of the lubricant and to keep dust and dirt out of the container. It is extremely important that lubricants be kept free of foreign matter.

Many of the bearings used in these equipments are made of oil impregnated bronze and require no lubrication.

The effects of overlubrication are almost as serious as those of underlubrication. Too much lubricant in ball and roller bearings prevents efficient operation and may cause a good deal of harm from the pressure that is built up in the bearings as they become warm. An excess will cause an overflow of the lubricant onto the machine. The overflow not only collects harmful dirt and grit, but necessitates more cleaning time. In some equipments, breakdowns have been traced to overlubrication. The oil tends to destroy electric insulation; careless handling of the lubricant can result in dirt being carried into bearings with the lubricant.

SPECIAL MAINTENANCE.—Shafts should be checked for dirt and corrosion. Dirt may be removed with an approved solvent. The shafts may also be cleaned with fine crocus cloth to remove obstinate dirt marks. Use a fine file or fine sandpaper to remove burrs. After cleaning, the shafts should be relubricated according to instructions.

Noise, loss of sensitivity, and improper tuning may be caused by faulty or dirty tuning capacitors. (Serious losses may also occur in certain other tuned circuits.)

Rotor contacts, bearings, and plates may be cleaned with an approved solvent. Pipe cleaners (if available) are especially useful for cleaning between capacitor plates. A small brush, dipped in solvent, may also be used for this purpose. Be careful not to damage or bend any of the plates.

Some relay contacts are plated with thin coats of silver. In cleaning this type of contact, avoid the use of abrasives, which may damage the contact surfaces. These surfaces are cleaned with solvent.

Pitted contacts on heavier relays, such as those used for power contact circuits, are cleaned with a fine grade of crocus cloth. Badly pitted contacts should be replaced singly, if possible; if not, a complete new relay may have to be installed. After being cleaned, the contacts of relays are finished with a burnishing tool.

The moving parts of relays are checked as follows:

1. Check the armature pivot points. They should be free of burrs, rust, corrosion, or any other defect that may prevent free movement. Remove burrs or corrosion with a fine file or fine sandpaper. However, be sure that the shape and location of the pivot points have not been changed.
2. The return spring should be inspected for correct tension. Replace the spring if rusted or damaged.
3. Examine the relay winding for damage to the insulation. Damaged wires or insulation may be repaired with tape or insulated tubing (spaghetti).
4. Check the relay core for corrosion. If corroded, the relay should be replaced to avoid possible future failure.
5. Check the frame; repair or replace if damaged.

Particular care should be used in checking the mating threads when examining jacks and plugs. Any damage to the threads will make it difficult, if not impossible, to mate the connectors. Clean off grease and dirt with solvent, using a firm, bristle brush. After cleaning and checking the plug or jack, only the threaded part should be relubricated with a thin film of grease. Avoid overlubrication.

Gears and racks must be checked for dirt and other foreign particles in the gear teeth. Clean off dirt or caked lubricant with a small brush dipped in solvent. The gear shafts may also be cleaned with the solvent. Polish the shaft with a piece of fine crocus cloth, if necessary. After cleaning, the gears and racks are relubricated according to the procedures described in the instruction book.

Wafer switches and detents should be examined carefully to ensure firm spring tension. Weak spots require restoration of spring tension. However, long telephone-type switch or relay contacts should never be bent. These contacts should be replaced, if possible. If the contacts cannot be replaced singly, the entire switch may have to be replaced, because poor contact pressure leads to trouble and eventual failure.

Check the detent actions and the switch shaft. These parts, as well as the switch contacts,

may be cleaned with solvent. The various detent assemblies, especially those in the various sub-units of the RFO, need careful attention. After a switch or detent has been cleaned, the part should be relubricated as directed in the instruction book.

When inspecting the miniature sprocket-type chains, be sure to check the adjustment of the sprocket idlers. Proper tension on the chains must be maintained at all times. To achieve correct tension, a balance must be found which is a compromise between ease of operation and minimum backlash. In case of severe damage to the chain, it should be replaced. Remove dirt and grease with solvent.

Radio Receivers

INSPECTION, CLEANING, AND ADJUSTMENT.—The instruction book for each radio receiver lists certain preventive maintenance procedures that must be followed if the equipment is to be maintained in peak operating condition. Of course the instructions will vary, depending on the particular type of receiver, but the preventive maintenance instructions listed below are typical.

The MONTHLY checks include the following: (1) Inspect to determine if the mounting bolts in the cabinet are tight, and tighten mounting bolts and all external fasteners when loose; and (2) inspect cords and plugs for wear and broken parts. Replace any cord that causes clicking sounds in the earphones when shaken during operation.

The QUARTERLY checks include the following: (1) Remove and replace the chassis in the cabinet. (If the chassis binds on the rails, adjust the chassis tilting fulcrum accordingly and lubricate according to the instruction book.); (2) check each plug-in unit for loose connections and appearance of the component. If the components show signs of overheating, apply corrective maintenance, as given in the instruction book; (3) inspect the chassis for loose interstage connectors (multisockets) on the chassis, and tighten as required; (4) inspect the band selector and reception control for loose crank pins that connect to the wafer shafts. If pins are loose they should be tightened according to the instructions given in the instruction book; and (5) remove dust from the chassis and assemblies by the use of a small blower. Remove excess lubricant from the band switch and reception control racks, miter gears, and dial gears. After the cleaning is accomplished, the equipment is lubricated according to instructions.

The SEMIANNUAL checks include the following: (1) Inspect spare assemblies for evidence of physical damage; (2) check alignment of tuning dial and the operation of the dial light.

Some of the checks already mentioned, and the important checks for sensitivity and selectivity, are somewhat involved and are treated separately in the following sections.

SENSITIVITY (GENERAL).—The one measurement which provides maximum information about receiver condition in field operation is that of sensitivity. This measurement ordinarily requires application of an input signal of variable voltage (which is accurately determined by calibration) to the antenna terminals of the receiver, through an impedance which approximates that of the antenna with which the receiver is designed to be used. Any external impedance, which is added to the signal-generator impedance to simulate the antenna impedance, is usually known as a dummy antenna. It insures that the signal current in the input circuit of the receiver is the same as would appear with the known signal induced in an ideal receiving antenna, and it also insures that the input circuit of the receiver is "loaded" the same as it would be by an ideal antenna.

In the 15 to 30,000 kc range, a typical standard dummy antenna for high-impedance-input receivers consists of a 20-microhenry inductor shunted by a series-connected 400-$\mu\mu$f capacitor and a suitable 400-ohm resistor, with the shunt combination in series with a 200-$\mu\mu$f capacitor, figure 7-23. This unit should be enclosed within a properly designed grounded shield and used with a signal generator having a resistance output impedance not exceeding 50 ohms. This dummy antenna "looks" like a 200-$\mu\mu$f capacitor at low frequencies, is a complex impedance in the 1-mc region, and

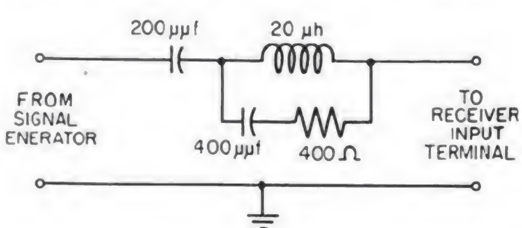

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Figure 7-23.—Dummy antenna circuit.

"looks" like a 400-ohm resistance at frequencies of 2 mc to 30 mc. For the measurement of low-impedance, receivers of 50 to 70 ohms nominal impedance, a signal generator with a 50-ohm output may be directly connected without the use of an external dummy antenna. Other generator impedances may require special dummy-antenna networks to load the generator and the receiver properly while allowing the induced antenna voltage to be accurately known.

For measurement of sensitivity, the receiver is adjusted for the type of reception desired, and facilities, such as tone controls or audio filters, AGC, silencer, and noise limiter, are placed in or out of operation as discussed later. The power line voltage applied to the receiver should be well within the normal recommended operating range. The receiver output terminals should be properly loaded. At the headphone or audio-line terminals, UNLESS OTHERWISE SPECIFIED IN THE INSTRUCTION BOOK FOR THE EQUIPMENT, the load should be a 600-ohm noninductive resistor (such as one of the composition type), capable of continuously dissipating the maximum receiver audio power output that can be produced at these terminals. High-impedance headphones may be used in shunt with the load for monitoring the output. Low-impedance phones may load the output appreciably and may have to be removed when data are being taken. The output voltage should be measured with a high-impedance audio voltmeter, capable of accurate indication from 0.1 volt to 100 volts, that will not appreciably load the output circuit. Although some receivers are equipped with audio-output meters, the meters provided may not indicate required standard noise levels with sufficient accuracy.

CW (A-1) and Facsimile (A-4) Sensitivity.— For CW (A-1) reception sensitivity measurements, some means must be provided to set the output beat note of the receiver to the standard 1000 cps frequency with reasonable accuracy (about 1000 ±50 cps). In some receivers the 1000 cps "sharp" audio filter provided has a bandwidth narrow enough to allow satisfactory adjustment of the beat note by centering the tone in the passband. The 1000 cps internal tone modulation frequency of most signal generators is also accurate enough and can be zero-beat against the output beat note. Alternatively, the output of a calibrated audio oscillator and that of the receiver may be fed independently to the deflection amplifiers of an oscilloscope to give the Lissajous pattern typical of synchronous waves for establishing the output frequency.

For determination of both keyed CW and facsimile reception (A-1 and A-4) sensitivity, the CW (beat-frequency) oscillator should be ON and the receiver audio gain should be set at maximum, with AGC, silencer, noise limiter, and the output limiter turned OFF. If not otherwise specified in the receiver instruction book, audio filters or tone controls should be set for maximum audio range. The antenna trimmer normally should be peaked at the high-frequency end of each band, and not reset at other frequencies. The signal generator is used unmodulated. Following these initial adjustments, the r-f gain control is adjusted to produce 60 microwatts of noise (0.19 volt across 600 ohms) with the receiver tuned to the desired frequency but with no input signal applied from the signal generator. The signal (carrier only) is then applied, and is tuned as nearly as possible to center on the noise of the overall r-f passband of the receiver, with the CW oscillator frequency control adjusted to the side of zero beat that produces the higher output with a 1000-cps beat note. The input-signal voltage is then adjusted to produce 6 milliwatts output (1.9 volts across 600 ohms), resulting in +20 db output signal-to-noise ratio with 0.1 db. The receiver sensitivity, in terms of input signal voltage, is then read from the signal-generator voltage calibration (see signal-generator instruction book to interpret voltage readings).

Phone (A-3) Sensitivity. —Phone (A-3) reception sensitivity measurement requires the application of a carrier modulated 30 per cent at 1000 cps. The r-f gain control should be set at maximum, with AGC ON and the CW (beat frequency) oscillator OFF, unless this condition is automatically established by a reception selector control (provided on some receivers). All other controls except the a-f gain control are then progressively adjusted until the receiver output noise level is 0.6 milliwatt (0.6 volt) with signal generator modulation OFF, and the signal-plus-noise output is 6 milliwatts with modualtion ON, which produces +10 db ratio of output signal-plus-noise to noise (10.4 db signal-to-noise ratio). The receiver sensitivity, in terms of input voltage, is then read from the signal-generator voltage calibration.

MCW (A-2) Sensitivity.—Tone modulation (A-2) reception sensitivity should be measured under the same conditions and using the same procedure as for A-3 reception sensitivity, except that the a-f gain is set at maximum with AGC OFF, and the r-f gain control and signal-generator output voltage are varied to produce standard sensitivity conditions. Also, the generator should be modulated 100 percent at 1000 cps, with standard output of 6 milliwatts signal-plus-noise and noise output of 60 microwatts for generator modulation (20 db output signal-to-noise ratio).

If the available signal generators cannot be used modulated 100 percent because of excessive frequency modulation or because of other limitations, an approximate sensitivity measurement may be made by employing 30 percent modulation to produce 6 milliwatts output with 10 db output signal-plus-noise to noise ratio. This procedure may give somewhat erroneous results, as detector modulation distortion or modulation clipping by built-in noise limiters may be much less at 30 percent than at 100 percent modulation of the carrier.

FSK Sensitivity.—If the receiver checks satisfactorily for CW (A-1) sensitivity, only the additional switching for FSK reception and any special FSK filters in the receiver could produce poor FSK operation, so far as the receiver proper is concerned. Therefore, the receiver may be checked for FSK sensitivity by initially checking its standard CW sensitivity. If this proves to be normal, switching to FSK operation will allow the output beat frequencies and audio output level to be checked to insure that they meet the requirements of whatever audio-type FSK converter is employed.

The output which the receiver can produce for an i-f type converter (if this facility is provided) may be checked with an electronic voltmeter capable of good accuracy at the intermediate frequency, with a range of 0.001 volt to at least 10 volts. The receiver and converter instruction books should be consulted for standards of receiver output in this case.

Reserve Gain.—Reserve gain for all types of reception may be determined by measuring the ratio of noise output at standard gain (the gain condition used in measuring standard sensitivity) to noise output at maximum gain, provided maximum gain does not produce any substantial degree of output overload or saturation. If saturation is approached or reached at maximum gain, the setting for standard gain should be noted, and the reserve gain determined with the aid of a gain control calibration curve, which can be obtained by subsequent measurement.

Gain Variation With Change of Frequency.—Gain variation over each band for any condition of reception may be determined by adjusting for standard gain (as for sensitivity measurements) at the high-frequency end of each band, and then noting the input-signal voltage required at various frequencies over the band to produce the same 6-milliwatt 1000-cps output.

OVER-ALL SELECTIVITY (GENERAL).—The term "over-all selectivity" usually refers to the frequency selectivity of a receiver as measured from (and including) the antenna to the input terminals of the final detector. It does not normally include any elements of the audio system.

The over-all selectivity of a superheterodyne receiver may be quite difficult to measure accurately with the equipment likely to be available in most operating installations, especially at frequencies above 1 mc. If the lowest signal frequency is at least several times that of the lowest intermediate frequency used in the receiver, the over-all selectivity is very likely to be practically the same as the lowest i-f selectivity. In such instances, the i-f selectivity curve may suffice and is much easier to measure.

Narrow-Band Receiver Selectivity.—For receivers with r-f or i-f bandwidth of less than about 5 kc at 6 db down (e.g., VLF and LF receivers), the measurement can be made as follows: The receiver should be adjusted for standard MCW (A-2) sensitivity conditions (AGC OFF), with a high-impedance d-c voltmeter connected to read the voltage across the final detector diode load. (It may be necessary to connect a 1-megohm isolating resistor between the "high" end of the diode load and the "high" lead of the voltmeter to prevent regeneration or other undesirable effects.) The signal generator is used unmodulated, and the signal voltage is increased from standard input in steps of about 1.4, 2, 3, 5, 10, 100, and 1000 times the standard input, in turn. At each step, the frequency of the signal is adjusted to produce the same detector diode voltage as previously obtained with standard input at

resonance. The signal-generator frequency-vernier dial reading is taken for each step at both sides of resonance. The reading recorded should always be obtained by approaching from the same direction of dial rotation for all readings, to minimize error resulting from signal-generator dial backlash. The signal-generator frequency dial can be calibrated, with higher precision than afforded by its markings in the range covered, by first noting the venier-dial settings for the two frequency-dial markings nearest the limit frequencies of the selectivity curve data and then dividing the difference in frequency by the corresponding number of vernier divisions to obtain kc per division. A curve can be plotted of "times resonant input voltage" on semi-log paper (or "db above resonant input" on linear paper) against "kc off resonance" on a linear scale. The points of greatest interest are usually those defining the 6 db down and 60 db down bandwidths, which also determine the 60/6 db bandwidth ratio (or selectivity ratio).

Selectivity of Wider-Band Receivers.—With receivers having 5 kc or more bandwidth at 6 db down on the selectivity curve, selectivity measurements may be made using a modulated carrier, provided that the rate of attenuation of the skirts of the curve is not too high (not more than about 6 db per kc). This means that, in general, TRF and single-conversion superheterodyne receivers designed for operation above 500 kc may be measured with a carrier modulated 30 percent by a 400- or 1000-cps tone. The procedure is the same as for unmodulated carrier selectivity measurement (as above), with the same receiver conditions, except that the output measurement is made at the audio output terminals of the receiver, just as for MCW (A-2) sensitivity (AGC OFF). The audio output is maintained at standard level, as the input-signal frequency is varied, by adjustment of the signal-generator carrier output voltage.

I-F Selectivity.—I-F selectivity may be measured in the same manner as over-all selectivity, except that it may be desirable to disconnect the input-signal circuit from the preceding frequency converter (mixer) to prevent that circuit from loading the signal generator. It will then usually be necessary to provide a grid-return resistor for the mixer (about 10,000 ohms), as well as a coupling capacitor (about 1000-$\mu\mu$f) from the mixer input grid to the signal-generator output, in order to prevent d-c return through the generator system. The oscillator should be disabled, by removing the oscillator tube or its supply voltages, if it appears to produce interference with the measuring signal. If this is done, the mixer output impedance will be changed somewhat, producing some change in i-f selectivity; however, the change is usually of a minor nature.

Primary Image Rejection.—The primary image rejection ratio provides a simple criterion of the preselector (front-end) alignment condition. To determine the primary image ratio, the receiver is first adjusted for standard MCW (A-2) sensitivity conditions. The signal generator is then tuned to produce maximum response at the primary image frequency (twice the i-f away from resonance, on the same side as the oscillator), and the input-signal voltage is adjusted to produce standard output. The ratio of the image input voltage to the standard sensitivity input (usually expressed in db) is the image rejection at the desired signal frequency. If the values obtained for this ratio over each band are within 3 db of the instruction book values and the sensitivity is normal, the front-end alignment is probably good.

TUNING-DIAL CALIBRATION.—Tuning-dial frequency calibration can be checked against any signal whose frequency is accurately known, such as that of radio station WWV and standard AM, FM, TV broadcast stations. Some receivers have built-in crystal calibrators which give signals spaced throughout the working range of the receiver. If none of these signals are available, it will be necessary to obtain a heterodyne frequency meter such as the model LR or FR-36, the output of which may be fed to the receiver antenna terminals and tuned in as an unmodulated CW signal. With any of these means, the tuning dial error should be carefully observed. If the error is excessive and shows a definite progression with frequency, the receiver may require realignment.

Tuning-Dial Backlash.—Tuning-dial backlash is usually best determined in the CW (A-1) reception condition, by first tuning in a CW signal to receiver resonance with rotation of the dial in one direction, and adjusting the beat-frequency oscillator, on the side of zero beat that gives the greater output, until a

1000-cps beat note accurate within ±5 cps is obtained. The vernier tuning dial (if provided) is then read as accurately as possible, or the tuning knob is marked in some suitable way. Following this, the signal is again tuned in, approaching it this time from the opposite direction of dial rotation; until the same 1000-cps indication is obtained on the same side of zero beat as before. The difference in vernier-dial divisions or in angular position of the tuning knob is the backlash.

Zero-beat output from the receiver might be used as a reference for this measurement instead of 1000 cps, which would allow dispensing with the oscilloscope and audio oscillator. However, because the audio response of most receivers at very low frequencies is not good, accurate determination of zero beat by ear or output meter is usually quite difficult.

RESONANT OVERLOAD.—The resonant overload characteristic (desired output vs signal-carrier-input voltage) should be determined with the receiver adjusted for standard sensitivity conditions for the type of reception desired (A-1, A-2, etc.). The receiver output voltage for increasing values of signal-generator input from 0.1 microvolt to maximum is recorded. In addition, in MCW operation, the output noise level at each input-signal level with modulation off but carrier on should be recorded. These readings, when plotted on log-log paper, can be interpreted to indicate linearity of receiver gain, residual hum, and hum modulation, etc. If resonant overload curves are obtained for different audio-gain-control (AGC ON) and output-limiter-control (AGC OFF) settings, respectively, the capabilities of the AGC system and of the limiter may be determined (for steady-state signal conditions). If resonant overload curves are obtained at different silencer or squelch-control settings over the working range, silencer characteristics and effectiveness of operation may be determined. These may be compared with report or instruction-book data on these characteristics.

FREQUENCY STABILITY.—Frequency stability with mechanical stress caused by inclination, shock, and vibration may be noted by observation of the receiver while it is subjected to these conditions during use, or various surfaces of the receiver may be pressed upon or pounded with the hands in bench tests. In either case, the effect of mechanical displacements of the receiver on the pitch of the output beat note at various receiver frequencies should be observed under the conditions of CW (A-1) reception. Relative comparisons can be made between different receivers of the same model by this procedure if it is suspected that a defect has developed in one of them. Similar simple tests can be made for microphonic elements.

Warmup frequency drift may be measured by setting a Model LR or similar frequency meter to give a 1000-cps beat-note output from the receiver (in A-1 reception condition) when the receiver is first turned on. Then, as the receiver drifts, the frequency meter is retuned at intervals to produce this same beat note, and the new frequency reading is recorded each time until the drift has essentially stopped. If the drift is small, the frequency meter may be left fixed, and the change in beat-note frequency observed instead. If the receiver is not designed for A-1 operation, a signal that will heterodyne with the i-f may be injected into the final detector through suitable loose coupling means, and the frequency meter used as directed above.

Frequency stability with gain change may be determined by feeding the maximum unmodulated carrier output of the signal generator to the receiver (as adjusted for CW (A-1) or FSK (AGC OFF) reception), and then turning the r-f gain control from maximum gain down until the output signal can just be heard. The change in output beat-note frequency should be less than 100 cps with a well-designed receiver intended for signals below 30 mc, and less than 10 cps below 1 mc. A similar test for receivers not designed for the above modes of operation can be made by using a heterodyning voltage injected into the second detector as described above. For such receivers, greater frequency changes are usually tolerable (up to 10 percent of the 6-db down bandwidth of the over-all selectivity curve).

Frequency stability with input-signal voltage change may be determined by noting the beat-note change during a CW (A-1) or FSK (AGC OFF) resonant overload measurement made as previously described. The same beat-note tolerances as above will apply. This test may be made on receivers without beat-frequency

oscillators by using auxiliary beating means as described above.

Noise (Interference) Measurements

Because of the increased number of electronic and electro-mechanical equipments required to meet modern military needs, the elimination or suppression of noise and radio interference produced by these equipments has assumed greater importance. Interference, it should be remembered, not only may restrict or prevent vital communications, but also may divulge to the enemy the position of a task unit during periods of radio silence.

Various test equipments called radio test sets or noise meters are available to the technician to aid in measuring and locating interference. However, a systematic and logical procedure must be followed to locate the offending noise. If the receiver antenna system is introducing the interference, disconnecting the antenna at the receiver input terminals will generally cause the noise to disappear or abate considerably. Noise being conducted through the power line will not be affected by the above procedure, except for that type of interference that requires cross modulation with a carrier to make itself evident. Also, noise generated within the receiver itself will not be altered. The above test is important when the sound of the interference appears similar to tube noise or power-supply hum. Caution must be observed when using this method on receivers that operate on the higher frequencies since a short length of antenna lead (or even an unshielded circuit) may be sufficient to pick up considerable interference when the source is close to the receiver.

When it is established that the antenna is picking up interference, it is necessary to determine the exact source. An effective method is to turn off all equipment operating in the vicinity; if the interference ceases, each individual equipment can then be restarted one at a time until the equipment, which causes the interference to reappear, is located. It is more advantageous to begin with all equipments shut down, rather than stopping individual equipments with other running because of the possibility that a weak source may be masked by a stronger source.

A common method of locating a noise source using a noise meter is to move about the suspected area with the instrument and observe the intensity on the indicating meter, or listen to the audio level with a headset. Since noise sources usually have a large gradient, it is often possible to proceed to the source of interference by walking in the direction of increasing readings. After locating the offending equipment, it is necessary to determine the particular part of the equipment that is responsible for the disturbance. This is accomplished, if possible, by judicious use of individual switches (or other means of disconnection) on various units of the equipment and by the use of probe antennas. Two types of probe antennas are available: the magnetic type, consisting of a small loop for magnetic pickup; and the electrostatic type, consisting of a length of shielded cable with about 5 inches of the insulated (but shield stripped) inner conductor extending for electric pickup. The shield covering the leads to the probe should be connected to the case of the noise meter. A probe antenna is effective only when broght close to the source, and is a great aid in locating the actual source.

A test equipment of the type used to measure radio interference is essentially a sensitive portable receiver covering a specified range of frequencies and capable of measuring noise levels and field intensities. (A representative type is Radio Test Set AN/URM-6). This type may be used as an r-f voltmeter to measure a voltage between two points. It differs from a conventional receiver, however, in two respects: (1) a time delay is introduced into the a-v-c circuit so that the output meter indicates the noise voltage in terms of the peak (or quasipeak) value, which is more significant than the average; and (2) the gain of the receiver is adjustable to previously calibrated levels to ensure uniformity of measurement on all frequencies. A calibrating signal source is included in the equipment for the latter requirements. For the former requirement a standard noise source is provided and is usually built into the test equipment. Briefly, it consists of a diode operating at saturation, the shot-effect noise of the tube providing a suffiently constant source of noise for calibration purposes. To maintain space current in the tube at saturation, a filament control (rheostat) is provided. For calibration procedure, the instructional literature that accompanies each test equipment should be followed in detail. In general, it should be noted that the above test equipments require extreme care and

careful maintenance to provide reliable service. Realignment and calibration are necessary at frequent intervals, especially if the equipments are often transported from place to place.

In conclusion, it should be stressed that equipments which normally do not produce noise, may do so when defective or in bad condition. This is particularly true of rotating or vibrating machinery. All commutators, slip rings, brushes, and brush holders must be in good condition. All normal ground connections to the frame or housing should be clean and tight. Movable contacts such as switch points and relay contacts should be clean and properly adjusted for minimum arcing. All shielded connections and bonding must make clean and tight electrical contact. Therefore, when the source of interference is located, corrective maintenance should be considered as part of the job of eliminating noise and interference.

CORRECTIVE MAINTENANCE

To perform effective corrective maintenance the CT M must have a good working knowledge of the basic principles of electricity and electronics. The only way to acquire this knowledge is by diligent study. The CT M must also be thoroughly familiar with the theory of operation of the equipments that he must service. A knowledge of the theory of operation can be acquired through a study of the "Theory of Operation" section (generally, section 2 of current instruction books) of the equipment instruction book. In the new technical manuals, a different procedure will be followed. This knowledge should be broadened to include other equipments at the earliest opportunity. As a matter of fact, CT Ms are generally rotated on the various electronic equipments so that their knowledge will be broadened and they will, therefore, be more valuable to the Navy.

Skill in the use of test equipment and hand tools is also necessary for effective corrective maintenance. Skill in the use of test equipment comes with practice and with careful study of the instruction book that comes with each piece of test equipment. The CT M should take advantage of every opportunity to learn more about every type of electronic test equipment used. The ability to use test equipment effectively is an absolute must for every well-trained CT M.

Chapter 8 of this training course will introduce the prospective CT M to some of the more common test equipments. Additional valuable information (both on test equipment and methods of troubleshooting) is contained in Handbook of Test Methods and Practices, NavShips 91828(A). A list of the various electronic test equipments (also troubleshooting methods) is included in the Electronics Installation and Maintenance Book, NavShips 900,000.

Importance of Tests and Measurements

Tests (for example, for opens, grounds, and shorts) and measurements (for example, current, voltage, resistance, frequency, and power) enable the technician to diagnose troubles so that repairs may be made. In many instances tests and measurements will indicate conditions that may be corrected before an actual breakdown occurs. Thus, tests and measurements (particularly measurements) are important both in preventive and corrective maintenance.

The purpose of any type of electronic test equipment is to measure accurately certain circuit values or to indicate certain circuit conditions. Each of these measurements or indications is used to determine the operating condition of electronic or electrical equipment. The accuracy with which measurements are made depends on the type of instrument used, its sensitivity, its rated accuracy, its useful range, and the care that the technician uses in making the measurement.

The exact procedure for making tests and measurements is given in the technical manuals (instruction books) that accompany the various electronic equipments.

Utilizing Results of Measurements

It should be emphasized that the mere taking of measurements means little unless they can be properly interpreted. For example, the presence of a direct potential across a grid resistor in an audio amplifier would mean little to a CT M unless he could interpret this in terms of a possible leaky coupling capacitor. In this connection, the necessity for a knowledge of basic circuit operation must be emphasized.

Before any attempt is made to interpret the results of measurements, an understanding of how the equipment operates should be acquired by a careful study of the applicable technical manual or instruction book.

The actual voltage, resistance, and current measurements that should be obtained are indicated in the circuit diagrams, charts, or in the performance standards or check-off books. The same is true of waveform measurements. Any deviation from the standard values (beyond the tolerance limits) means that some component is not doing the job that it should. By applying effect-to-cause reasoning, the defective component may be located. This is, of course, a job for a skilled technician.

Isolating the Fault

According the the "quals," the CT M must be able to localize equipment casualties to components of a system of electronic equipment; he must be able to localize electronic equipment casualties to parts or subassemblies and to make the repair by replacement of subassemblies or parts. However, it is conceivable that under certain circumstances, especially at smaller activities the CT M may have to effect the entire repair. In any case, the "quals" spell out only the minimum qualifications for advancement in rating, and the prospective CT M should in no way restrict his knowledge or his ability to make repairs.

There are numerous ways to isolate a fault to a component of a system, depending on the type of equipment. The technician must, first of all, know what each component does before he can know that it is not functioning properly.

The best way (the most economical in time and effort) to isolate a fault is by the use of the troubleshooting chart in the instruction book. By far, the largest section of the average instruction book is the one devoted to corrective maintenance. This is the section written especially for the technican; and for him it will very likely be the most valuable part of the book.

CHAPTER 8

PRACTICAL APPLICATION OF TEST EQUIPMENT

One of the most important parts of the CT M training program is learning to use test equipment in all types of maintenance work. To be effective in his work, the CT M must become familiar not only with the common types of measuring instruments (like the ammeter, voltmeter, and ohmmeter) but also with the more specialized equipment like oscilloscopes, dual-trace oscilloscopes, power and frequency meters, and impedance bridges.

The purpose of this chapter is to acquaint the technician with the practical use of test equipment. A cabinet or room full of test equipment is of little value if the technicians are not familiar with its use. Also, outdated or specialized equipment for testing or servicing electronic equipment that is no longer aboard is of no value.

The next most important thing, after learning how to use a test instrument, is to learn how to take the proper care of the instrument. Practically no test instrument will stand up under abuse. A damaged test instrument that reads incorrectly is, in many instances, worse than having no instrument at all. A large percentage of test equipment failure can be avoided by careful handling, proper use of the equipments, and proper stowage.

Much of the theory of operation and the practical application of the basic types of test instruments used in electric power and lighting circuits are included in Basic Electricity, NavPers 10086-A. A brief treatment of electronic test equipment is included in Basic Electronics, NavPers 10087-A. It is suggested that you review that material at this time. Additional practical information will be found in the latest edition of Handbook of Test Methods and Practices, NavShips 91828, and in the instruction books that accompany the various equipments. Another very valuable source of information is Electronic Test Equipment Application Guide, NavShips 91727. This publication lists the preferred electronic test equipment in current use by the Navy and gives the characteristics of each piece of equipment.

Some idea of the extent of the test equipment needed at an installation may be gained from the following list of equipments used for testing electronic gear. The list is not complete; however, it is representative.

- Nonelectronic Multimeter, AN/PSM-4;
- Electronic Multimeter VTVM, AN/USM-116 or HP-410B;
- Tube Tester, TV-10/U;
- Oscilloscope, AN/USM-105 or Tektronix 535/545;
- Capacitance-Inductance-Resistance Bridge, ZM-11/U;
- Audio Frequency Signal Generator. HP-200;
- Radio Frequency Signal Generator, AN/URM-25;
- Frequency Meter, FR-36/U;
- Frequency Counter, HP-542C/D;
- Teletype Distortion Analyzer, AN/GGM-1;
- Transistor Tester, TS-1100/U;
- A-C Vacuum Tube Voltmeter, HP-400D.

TYPES OF MEASUREMENTS

CAPACITANCE, INDUCTANCE, AND IMPEDANCE MEASUREMENTS

Combination capacitance, inductance, and resistant measuring instruments commonly make use of some type of bridge arrangement employing standard units of capacitance, inductance, and resistance and some means (for example, a meter) of determining bridge balance. If C, L, and R are determined, X_c and X_1, and Z may be computed for a chosen frequency. An elementary bridge circuit is treated in Basic Electronics, NavPers 10087-A.

The Capacitance - Inductance - Resistance Bridge, Type ZM-11/U can be used for measuring other quantities in addition to C, L, and R.

It measures the turn ratios of transformers, the dissipation factor of inductors and capacitors, the storage factor (Q) of inductors at 1000 cps, and insulation resistance of capacitors and other parts, as well as leakage in electrolytic capacitors when direct current is used.

POWER MEASUREMENTS

D-c power measurements and power measurements at power frequencies are treated in Basic Electricity, NavPers 10086-A, and will not be repeated in this training course.

Measurements of r-f and a-f power are also important and will be included in this chapter. Measurements of r-f power require special equipment and special techniques. Therefore the methods of making radio power measurements will be described in some detail.

In the audio-frequency range, power-level measurements are usually expressed in decibels (db) or decibels with a reference level

Table 8-1.—Relation of Power to ±DBM.

± DBM	Milliwatts for (+DBM)	Milliwatts for (-DBM)	± DBM	Watts for (-DBM)	Microwatts for (-DBM)	± DBM	Kilowatts for (+DBM)	Micro-microwatts for (-DBM)
0	1	1	30	1	1	60	1	1,000
0.5	1.122	0.891	31	1.259	0.794	61	1.259	794
1.0	1.259	0.794	32	1.585	0.631	62	1.585	631
1.5	1.412	0.708	33	1.995	0.501	63	1.993	501
2.0	1.585	0.631	34	2.512	0.398	64	2.512	398
2.5	1.778	0.562	35	3.162	0.316	65	3.162	316
3.0	1.995	0.501	36	3.981	0.251	66	3.981	251
3.5	2.239	0.447	37	7.943	0.200	67	5.012	200
4.0	2.512	0.398	38	6.310	0.158	68	6.310	158
4.5	2.818	0.355	39	5.012	0.126	69	7.943	126
5.0	3.162	0.316	40	10.00	0.100	70	10.00	100
5.5	3.548	0.282	41	12.59	0.0794	71	12.59	79.4
6.0	3.981	0.251	42	15.85	0.0631	72	15.85	63.1
6.5	4.467	0.244	43	19.95	0.0501	73	19.95	50.1
7.0	5.012	0.200	44	25.12	0.0398	74	25.12	39.8
7.5	5.623	0.178	45	31.62	0.0316	75	31.62	31.6
8.0	6.310	0.158	46	39.81	0.0251	76	39.81	25.1
8.5	7.080	0.141	47	50.12	0.0200	77	50.12	20.0
9.0	7.943	0.126	48	63.10	0.0158	78	63.10	15.8
9.5	8.913	0.112	49	79.43	0.0126	79	79.43	12.6
10	10.00	0.100	50	100.0	0.0100	80	100.0	10.0
11	12.59	0.0794	51	125.9	0.00794	81	125.9	7.94
12	15.85	0.0631	52	158.5	0.00631	82	158.5	6.31
13	19.95	0.0501	53	199.5	0.00501	83	199.5	5.01
14	25.12	0.0398	54	251.2	0.00398	84	251.2	3.98
15	31.62	0.0316	55	316.2	0.00316	85	316.2	3.16
16	39.81	0.0251	56	398.1	0.00251	86	398.1	2.51
17	50.12	0.0200	57	501.2	0.00200	87	501.2	2.00
18	63.10	0.0518	58	631.0	0.00158	88	631.0	1.58
19	79.43	0.0126	59	794.3	0.00126	89	794.3	1.26
20	100.0	0.0100	60	1,000.0	0.00100	90	1,000	1.0
21	125.9	0.00794				91	1,259	0.794
22	158.5	0.00631				92	1,585	0.631
23	199.5	0.00501				93	1,995	0.501
24	251.2	0.00398				94	2,512	0.398
25	316.2	0.00316				95	3,162	0.316
26	398.1	0.00251				96	3,981	0.251
27	501.2	0.00200				97	5,012	0.200
28	631.0	0.00158				98	6,310	0.158
29	794.3	0.00126				99	7,943	0.126
30	1,000.	0.0010				100	10,000	0.100

of one milliwatt (dbm). The technician must therefore become familiar with these units. (See table 8-1.)

In the LF, MF, HF, and VHF bands, a dummy antenna and a thermocouple ammeter may be used to obtain reasonably accurate measurements of the power output of a transmitter.

In the UHF and higher portions of the r-f spectrum, special power-measuring equipments employing bolometers are used.

In d-c circuits, power is the product of the current through a component and the voltage appearing across the component. Actually, if the resistance of the component is known, the power can be determined by the use of only one instrument (ammeter or voltmeter). The three basic power formulas are

$$P = E \times I$$

$$P = \frac{E^2}{R}$$

$$P = I^2R.$$

If the resistance is unknown, it may be determined by the use of an ohmmeter or a resistance bridge.

Below the UHF band, it is usually possible to measure the effect of a-c power directly in much the same manner as d-c measurements are made. In fact, modifications of this basic procedure utilizing the thermocouple ammeter are commonly used. The following power relationship is applicable:

$$P = I^2R,$$

where P is the power delivered by the transmitter, I is the r-f current in the antenna, and R is the effective resistance (principally radiation resistance) of the antenna.

A typical circuit for determining antenna input power is shown in figure 8-1. The meter may be calibrated to indicate the square of the current. The input power is equal to the product of the meter reading and the antenna effective resistance. Several methods are used for determining the effective resistance of the antenna. They include the VARIATION, SUBSTITUTION, and BRIDGE methods.

The R-F BRIDGE METHOD of determining the impedance of an antenna is both rapid and accurate, if shielding is sufficient and if the connections are properly made. The exact method of making the measurements with a bridge depends on the type of bridge used.

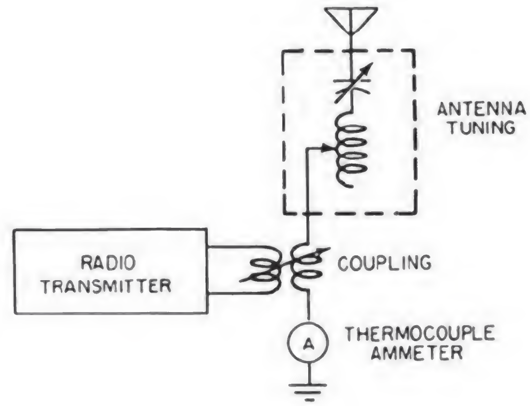

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Figure 8-1.—Typical circuit for measuring antenna input power.

R-F POWER METERS may be used to obtain a direct reading of the power output of a transmitter when a high degree of accuracy is not required and the power output is less than 500 w. With proper termination of the transmission line, the standing-wave ratio will be negligible, and essentially all of the power will be absorbed in the power meter.

There are several indirect methods of measuring r-f power—for example, the lamp-load, resistor-load, and bolometer methods.

In the LAMP-LOAD METHOD a pair of identical lamps are placed side by side. One lamp is fed by the r-f source, and the other is fed by a d-c source through a potentiometer. An ammeter is connected in series with the lamp fed by the d-c source, and a voltmeter is connected across the lamp.

The potentiometer is varied until the lamp fed from the d-c source has the same brilliancy as that of the lamp fed from the r-f source. The d-c and r-f power dissipated in the lamps are then equal. All that is necessary to determine the power dissipated in the lamp connected to the r-f source is to multiply the ammeter reading by the voltmeter reading.

To make the readings more accurate, a photoelectric cell may be used with a sensitive meter to determine when the lamps have the same brilliancy. It is assumed, of course,

that the transmission line feeding the r-f energy to the lamp is properly terminated in the lamp.

In the RESISTOR-LOAD METHOD of measuring r-f power the temperature rise of a noninductive resistor fed by the r-f power is determined by means of thermocouples placed in a stream of air that is blown over the resistor. This method is somewhat involved in that the rate of air flow and the temperature rise must be determined before the power dissipation can be calculated.

BOLOMETER METHODS of measuring r-f energy, especially in the UHF range, are becoming standard procedure. The bolometer is a loading device that changes in resistance as the power dissipated in it changes. The two main types of bolometers are the thermistor and the barretter. Their changes in resistance with temperature change are opposite. When the thermistor dissipates more power (increased temperature) its resistance decreases; when the barretter dissipates more power, its resistance increases.

Regardless of which type of bolometer is used, the method of making power measurements is essentially the same. The resistance of the bolometer is measured before and after the application of r-f power. A d-c source of power, which may be varied, is then connected to the bolometer, and the power is adjusted to give the same change in bolometer resistance as was obtained when r-f power was applied. The readily measured d-c power is equal to the r-f power. A bridge arrangement calibrated in units of power is commonly used along with the necessary attenuation devices. The thermistor is more widely used because of the high degree of precision that can be obtained, especially when compensating thermistors are used.

Because of the low power that the thermistor is capable of dissipating (1 mw is standard), the power must be attenuated before it is applied to the thermistor bridge. The amount of attenuation must be accurately known before the r-f power being measured can be determined.

ANTENNA RESISTANCE MEASUREMENTS

Basic Variation Method

This method of making antenna resistance measurements is illustrated in figure 8-2A.

The antenna resistance at the natural frequency of the antenna (tuning network not used—that is, L and C in ZERO positions) is determined first. The antenna is connected to ground through the coupling coil and the milliammeter, A; the shorting switch is in the CLOSED position (R_s is out of the circuit). Care should be taken to ensure that no signal is coupled to the antenna except through the coupling coil.

The r-f oscillator is then tuned to the resonant frequency of the antenna system. There should be a gradual dip in the grid-circuit milliammeter (not shown in the figure), reaching a maximum at the resonant frequency of the antenna system. If the dip in grid current is too abrupt, the coupling should be reduced. At the instant of lowest grid-current reading, the antenna milliammeter reading (I_a) should be maximum. The precision resistor, R_s, is next inserted in the antenna circuit (by opening the shorting switch), and the antenna current, I_s, is again read. During these readings no adjustments should be made in the coupling (the voltage induced in the antenna secondary should be constant). The antenna resistance, R_a, is determined by the formula,

$$R_a = \left(\frac{I_s}{I_a - I_s}\right) R_s.$$

Example: Find the antenna resistance if the antenna current is reduced from 2.5 amperes to 1.0 ampere after inserting a standard resistance of 60 ohms.

$$R_a = \frac{1.00}{2.50 - 1.00} (60) = 40 \text{ ohms.}$$

The frequency of transmission is not necessarily the same as the natural frequency of the antenna.

The resistance of the antenna at the frequency of transmission is next determined. The tuning network is connected into the circuit to resonate the antenna to the frequency of transmission. The shielding eliminates stray coupling paths.

The antenna is tuned to resonance (by means of the tuning network) at the frequency of transmission, and the current readings are taken with R_s out of the circuit and with R_s in the circuit, as was done previously. R_a is computed the same as before.

The same procedure should be repeated for frequencies above and below the natural resonant frequency of the antenna and a graph (essentially a straight line) of antenna resistance vs frequency plotted. Antenna resistance without the tuning network should not vary greatly from the antenna resistance with the tuning network.

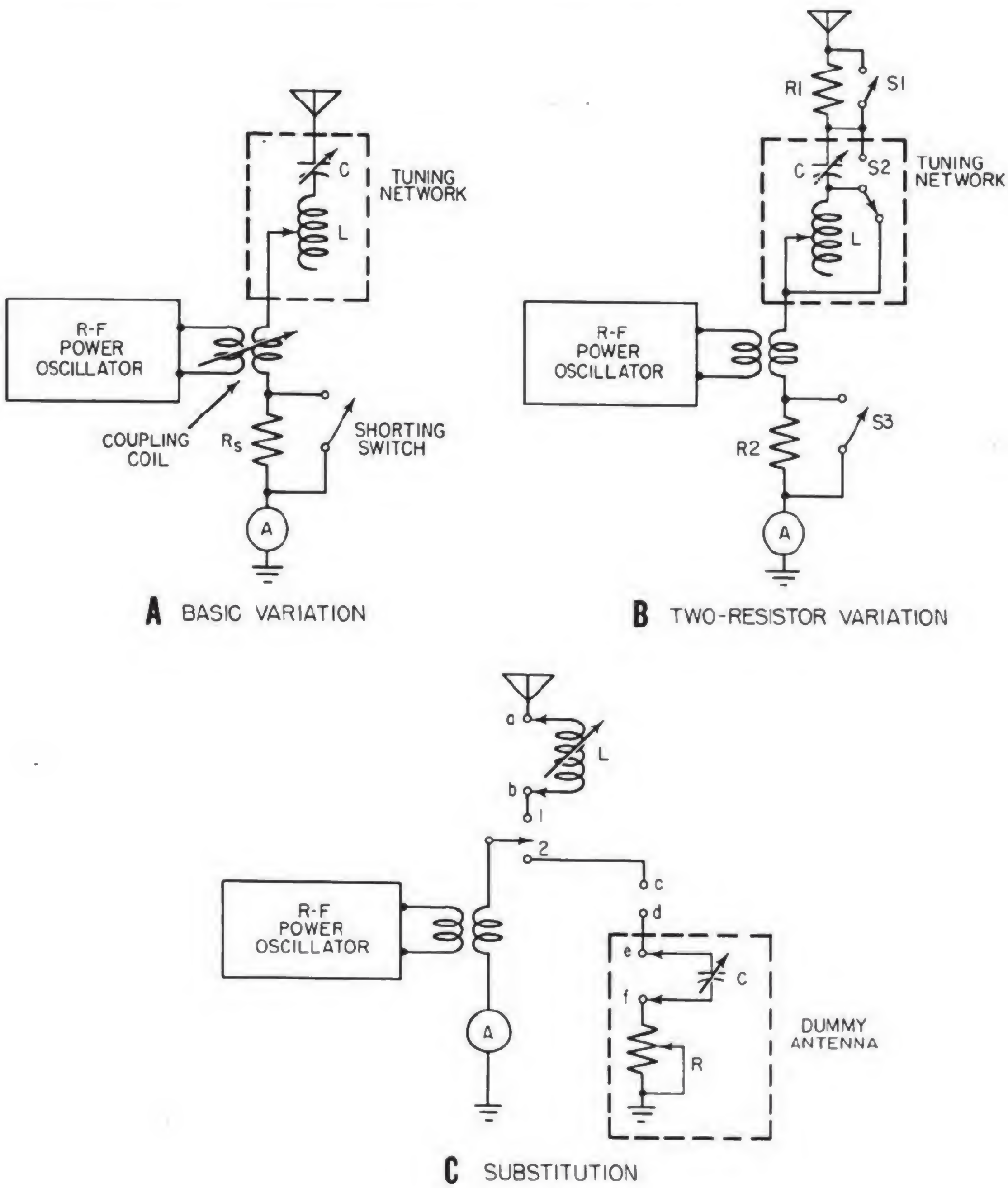

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Figure 8-2.—Methods of making antenna resistance measurements.

Two-Resistor Variation Method

This method of making antenna resistance measurements is helpful in determining if stray capacitive paths to ground are shunting the system. Although a variable inductor and capacitor are shown (fig. 8-2B), it is likely that only one or the other would be used. The inductor or capacitor should have calibrated dials. Two standard resistors are used instead of the single resistor that was used in the previous method. One resistor is located on the grounded side of the antenna transformer secondary; the other is located on the antenna side of the tuning network.

At the beginning of the test, both resistors are shorted out of the circuit, and the antenna circuit is tuned to the frequency of transmission (to the frequency of the oscillator). The oscillator output is then adjusted to produce the desired deflection, I_a, on the r-f milliammeter in the antenna circuit. No readjustment of the output should be made during the remainder of the test.

Switch S1 is then opened to insert R1 into the antenna circuit, and the antenna current, I_a, noted.

The antenna resistance, R_a, is computed by the formula that was given previously.

Next, S1 is closed to short out R1, and S3 is open to place R2 in the antenna circuit. The antenna resistance, R_a, is again computed by means of the formula.

If the two values of R_a do not agree, there is appreciable stray capacitance between the measuring circuit and ground or elsewhere. Proper grounding, shielding, and arrangement of the components will permit the two readings to be essentially the same.

The reactance of the antenna at the frequency of transmission may be determined by noting the value of L or C that is required to resonate the system. If C is required, the reactance of the capacitor will be

$$X_c = \frac{1}{2 \pi fC}$$

The antenna reactance, X_L, will have the same magnitude as X_c. If L is required to resonate the system, the reactance of the inductor will be

$$X_L = 2 \pi fL.$$

The antenna reactance, in this case, X_c, will have the same magnitude as X_L.

Substitution Method

This method of making antenna resistance measurements is illustrated in figure 8-2C. In this method, the antenna is replaced by equivalent amounts of reactance and resistance (a dummy antenna). Before making the resistance measurements, the antenna system is made resonant at the operating frequency. The oscillator should be well shielded and a fairly high energizing current should flow in the antenna circuit.

The antenna current is noted when the switch is in position 1. The switch is then placed in position 2. If a coil is used to resonate the antenna, as indicated in the figure, a capacitor will be used in the dummy antenna. If a capacitor is used to resonate the antenna, an inductor will be used in the dummy antenna. The antenna tuning element (inductor in this case) is then connected between points C and D, and the capacitor is tuned to resonance, as indicated by a maximum deflection of the milliammeter. The resistance of R is then varied until the meter reads the same as it did when the antenna was connected in the circuit. The resistance of R is equal to the antenna resistance, and the reactance of C is equal to the reactance of the antenna circuit (with the coil shorted out) at the resonant frequency.

FREQUENCY MEASUREMENTS

It is necessary to make frequency measurements to ensure that electronic equipments remain on the assigned frequency.

Radio transmitters must be maintained on their assigned frequency (within the allowable deviation limits) in order not to interfere with other transmitters. It is also obvious that if the receiver is pretuned to a set frequency, and the transmitter is off frequency, communication may not be established. It is therefore important that a primary frequency standard be established so that frequency meters (secondary standards) may be accurately calibrated and used to keep the transmitters and receivers on frequency.

The primary frequency standard is supplied by the National Bureau of Standards (NBS) from radio stations WWV in Beltsville, Md., WWVH in Maui, Hawaii, WWVB and WWVL in

Ft. Collins, Colorado. Additionally, the U.S. Navy broadcasts time and frequency standards from radio stations, NBA, NPG, NPM, NPN, and NSS. The schedule of services offered by these stations is published in Radio Navigation Aids, H.O. 117 A and B, issued by the USN Oceanographic Office. Table 8-2 lists the major characteristics of the NBS station.

To maintain its communications equipment on frequency, the Navy supplies excellent secondary frequency standards. These are discussed later in this chapter. Of course, the secondary frequency standard is of little value unless it is accurately calibrated against a primary standard.

FIELD-INTENSITY MEASUREMENTS

The field intensity, or strength, of a radio wave at a given point is, in most cases, a measure of the strength of the electric field component of the wave at that point. It is usually measured in terms of the number of millivolts or microvolts induced in an antenna one meter long.

Several types of test equipments for measuring field strength and interference are available to the technician. They are known generally as noise-field intensity meters. With this equipment, it is possible to measure either the RELATIVE or the ABSOLUTE magnitude of the field intensity produced by the energy radiated from an antenna. By the use of these instruments the directivity of an antenna may be determined, favorable antenna sites may be discovered, field patterns of an antenna may be plotted, and spurious radiation detected.

The measurement of relative field strength can be done with simple test equipment. It may consist of only a grid-dip meter or a pickup antenna, a tuner, a rectifier, and a microammeter.

For measuring the absolute field strength, more elaborate equipment is needed.

INTERFERENCE MEASUREMENTS

A brief treatment of interference (and field-intensity) measurements is included in Basic Electronics, NavPers 10087-A. Instruments

Table 8-2. —Major Characteristics of NBS Radio Stations.

	WWV	WWVH	WWVB	WWVL
Location	Beltsville, Md	Maui Hawaii	Ft. Collins, Colorado	Ft. Collins, Colorado
Frequencies	2.5, 5, 10, 15, 20, 25 Mc/s	5, 10 15, MC/s	60 kc/s	20 kc/s
Services				
Standard Radio Frequencies	Yes	Yes	Yes	Yes
Time Signals	Yes	Yes	Yes	No
Standard Audio Frequencies	Yes	Yes	No	No
Standard Musical Pitch	Yes	Yes	No	No
Radio Propagation Forecasts	Yes	Yes	No	No
Geophysical Alerts	Yes	Yes	No	No

similar to those used in making field-intensity measurements are used. One of the simplest methods of locating the source of noise interference is to move about with the noise meter in the suspected area and listen to the audio output by means of a headset. It is often possible to locate the source of interference simply by walking in the direction that gives the largest volume of noise.

Two types of antennas are available for close work: the probe and the loop. The probe is a short wire antenna (approximately 1 ft in length) and operates by electrostatic induction; the loop (approximately 1 ft in diameter) operates by electromagnetic induction. These antennas will often permit the discovery of the individual item in an equipment that is causing the interference—for example, a sparking relay contact.

THE NONELECTRONIC MULTIMETER

The multimeter AN/PSM-4A (fig. 8-3) is a typical multipurpose unit of test equipment which is widely used in the Naval Security Group. it is a completely portable volt-ohm-milliammeter and can be used to measure direct current, resistance, and d-c/a-c voltage output. The complete unit includes test probes which may be used with their prod tips, or the tips can be fitted with alligator clips or a telephone plug to simplify most contact arrangements and connections. A high-voltage probe is also included, which makes it possible to read

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Figure 8-3.—Multimeter AN/PSM-4A, Front View with Cover Open.

voltages up to 5000 volts direct current. This probe contains a warning light to indicate the presence of high voltage.

Multimeter AN/PSM-4A is designed to make the following electrical measurements:

(1) It will measure direct currents up to 10 amperes.
(2) It will measure resistances up to 300 megohms.
(3) It will measure d-c voltages up to 5000 volts.
(4) It will measure a-c voltages up to 1000 volts (RMS).
(5) It will measure Output voltages up to 500 volts (RMS).

The following paragraphs each have a block diagram which shows the general layout of the circuit within the instrument part of Multimeter AN/PSM-4A, as it is arranged when used to measure voltage, current, or resistance. The Red Test Lead and the Black Test Lead are the probes which are connected into the circuit being measured. The current which passes through the meter movement causes the meter to indicate the values on the dial. When measuring high d-c voltages, the High Voltage Probe and the Black Test Lead must be used.

D-C VOLTAGE CIRCUITS

Figure 8-4 shows the block diagram of the circuits for measuring d-c voltages. The circuit is selected with function switch S-101, in either its DIRECT or REVERSE DCV position. For voltages up through 500 volts, a range is selected with range switch S-102. For the 1000 volt range, the Red Test Lead connects the special 1000 V.D.C. jack, and the range switch is not in the circuit. For the 5000 volt range, the High Voltage Probe connects the special 5000 V.D.C. jack, and places its resistance in series with the meter movement. For any range, the total resistance of the meter movement and the multiplier resistance in series with it will regulate the meter current to provide a proportional current to indicate the amount of voltage in the circuit.

A-C AND OUTPUT VOLTAGE CIRCUITS

The circuits which measure alternating current and output voltages are selected with the ACV and OUTPUT positions of function switch S-101 as shown in figure 8-5. For voltages up through 500 volts, a range is selected with range switch S-102. For the 1000 volt range, the Red Test Lead connects the special 1000 V.A.C. jack, and the range switch, S-102, is not in the circuit. The a-c voltage impressed across the circuit between the Red and Black Test Leads sends current through the resistance of the circuit in both directions, but the rectifier, CR-101, allows only one direction of current flow through the meter movement. Current passing in the opposite direction flows in an alternate circuit around the meter movement. The meter is calibrated to indicate the RMS value of the a-c voltage applied to the instrument circuit.

D-C CURRENT CIRCUITS

The circuit which measures direct current is selected with the DC uA MA AMPS position of function switch S-101. (See figure 8-6.) For currents up to 1000 milliamperes, the range is selected with range switch S-102. For the 10 ampere range, the Red Test Lead connects the special 10 AMPS jack, and range switch S-102 is not in the circuit. Each range provides a parallel shunt resistance for the meter resistance, and the circuit current divides between these two parallel paths. The proportional part which passes through the meter movement indicates the total circuit current.

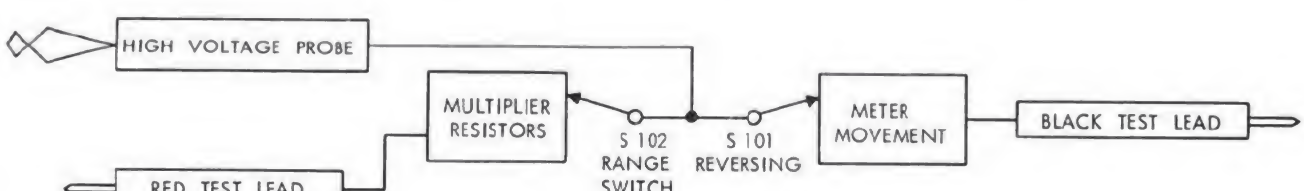

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Figure 8-4.—Functional block diagram of DC Voltage Circuits.

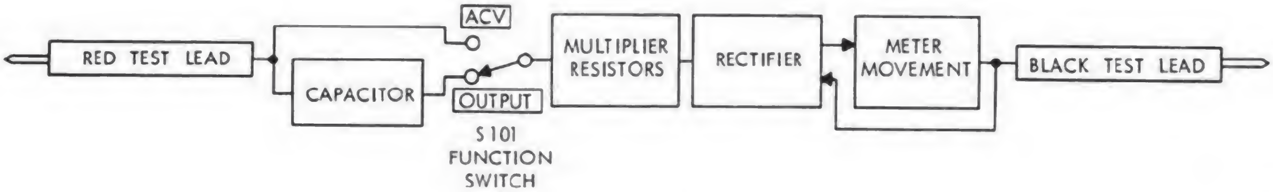

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Figure 8-5.—Functional block diagram of AC and Output Voltage Circuits.

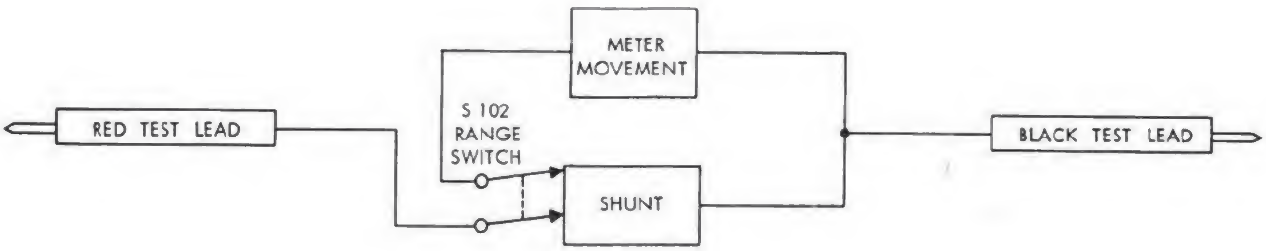

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Figure 8-6.—Functional block diagram of DC Current Circuits.

OHMMETER CIRCUITS

The ohmmeter circuit and its ranges are selected with function switch S-101. (See figure 8-7.) Its positions are Rx1, Rx10, Rx1000, and Rx10000. An internal battery furnishes the power for all resistance measurements. For each range, the circuit is arranged so the meter will indicate zero ohms, and full scale deflection, whenever the Red Test Lead and the Black Test Lead are shorted together. When you connect any resistance between the test leads, this resistance will be in series with the instrument circuit, and less current will flow through the meter movement. The amount of reduced meter deflection indicates how much resistance is between the test leads.

THE ELECTRONIC MULTIMETER

Multimeter AN/USM-116 is a portable, combination electronic instrument used for general servicing of electronics equipment. It is designed for use where precise voltage, current, and resistance measurements are required. It provides a direct reading of values on a single indicating meter mounted on the control panel (see figure 8-8). A high input-impedance permits voltage measurements to be made with only a small percentage of loading on the circuit under test. The multimeter can measure the following: Alternating current voltages and radio frequency voltages which are indicated in rms values; (actual deflection is proportional to the rectified peak value) d-c volts, d-c current, and resistance. The specific range for each of these functions is listed as follows:

(1) A-c volts: 0.01 to 300 in rms values.
(2) D-c volts: 0.02 to 1,000.
(3) D-c current: 20 microamperes to 1,000 milliamperes.
(4) Resistance: 0.2 ohm to 1,000 megohms.

To understand the principles upon which the operation of Multimeter AN/USM-116 is based, refer to figure 8-9 while reading the following explanation.

The multimeter can measure a-c and d-c voltages as well as resistance and current. When measuring a-c voltages, the signal is first rectified by the diode in the probe. The signal must be rectified because the meter circuit is sensitive only to d-c voltages. When d-c voltages are measured, the a-c probe containing the diode rectifier is not needed.

The d-c or a-c voltage to be measured is applied across a voltage-divider network so that

the total input impedance of the multimeter remains constant when the position of range switch S2 is changed for various levels of input voltage.

The meter is connected across a balanced bridge network. With no input, the bridge circuit is balanced and the meter reads zero. When the bridge is unbalanced by an input voltage, the meter pointer is deflected up-scale. The extent of deflection is in proportion to the strength of the input voltage. The meter actually measures peak a-c voltage (on the a-c function) but it is calibrated in rms values.

Switch S1 is used to select the desired function. When measuring d-c voltages, it may also be used to change the polarity of the multimeter from +DC to -DC, thereby eliminating the necessity of reversing the test leads.

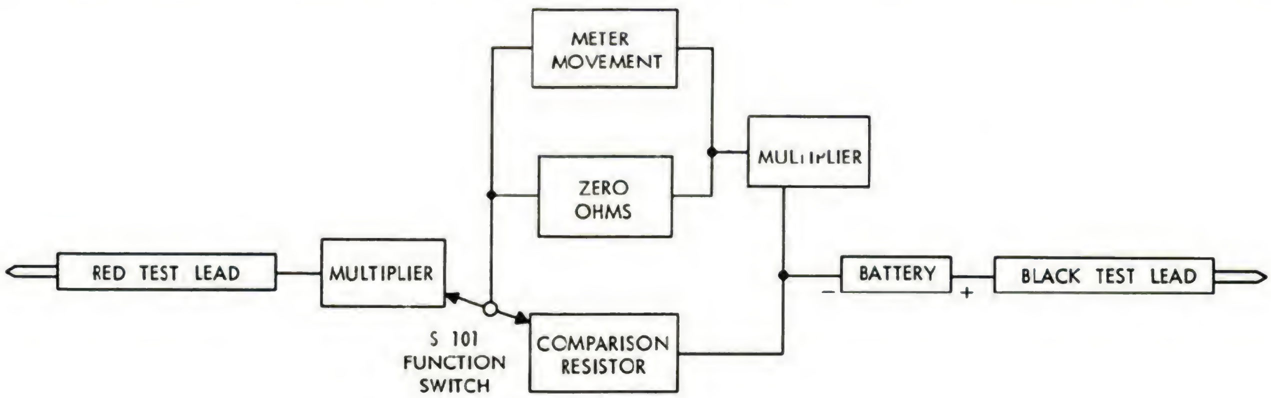

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Figure 8-7.—Functional block diagram of Ohmmeter Circuits.

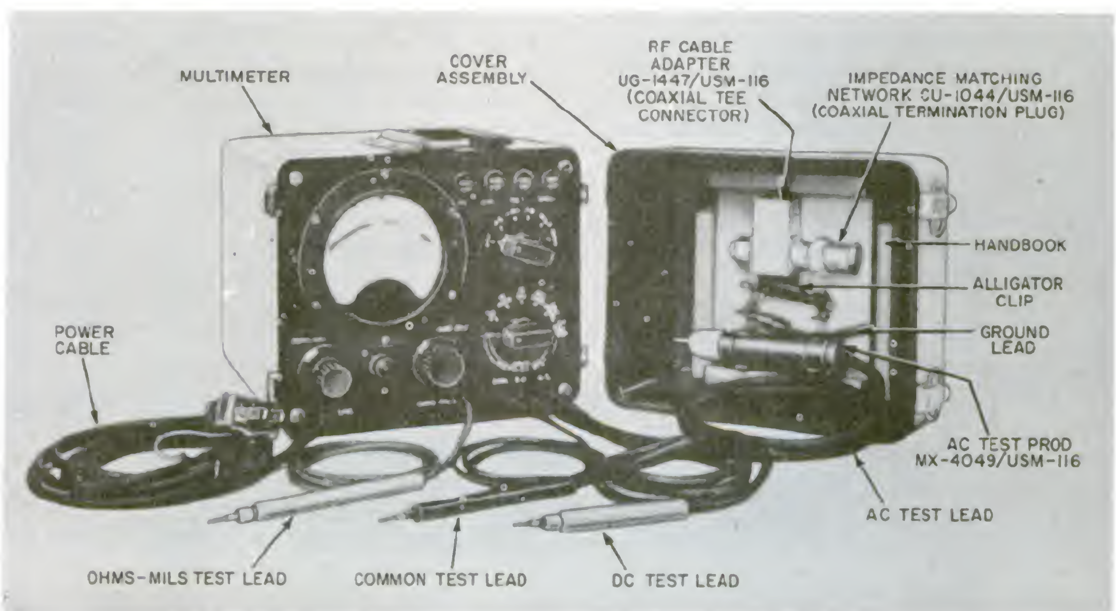

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Figure 8-8.—Electronic Multimeter AN/USM-116.

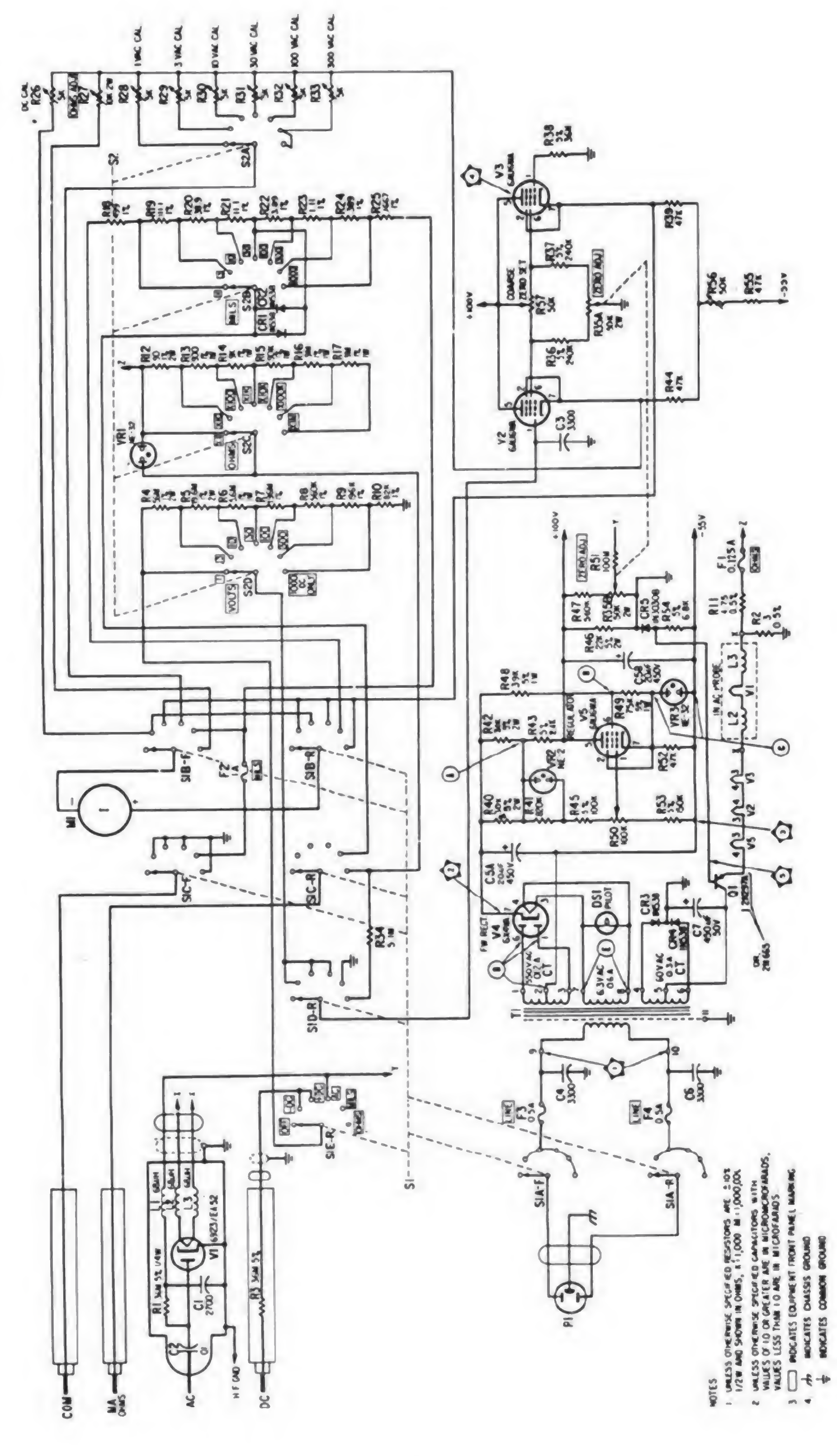

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Figure 8-9.—Electronic Multimeter AN/USM-116, schematic diagram.

Switch S2 is used to connect the necessary resistance into the circuit for each range. The resistance across the voltage-divider networks reduces the input signal to a level suitable for application to the bridge. There are three voltage-divider networks, one for each function.

The ohmmeter section also utilizes the bridge circuit. When an unknown resistance is placed between the OHMS-MILS lead and the COM lead, the bias voltage on V2 decreases in proportion to the unknown resistance. The value of the unknown resistance determines the degree to which the bridge is unbalanced and hence the magnitude of the meter pointer deflection. No battery supply is required for the ohmmeter circuitry.

The milliammeter function does not make use of the bridge circuit. The range switch S2 connects various shunts across the meter to increase the range of current measurement.

A voltage regulator V5 tends to maintain the B+ supply voltage to tubes V2 and V3 at a constant value despite changes in line voltage. Each of these circuits is described in greater detail in the following paragraphs.

Two other commonly used vacuum tube voltmeters, the HP-400D and the HP-410B, are shown in figures 8-10 and 8-11. The HP-400D is an a-c VTVM and can be used to measure a-c voltages as low as .0001 volts rms. It can also be used as an a-c preamplifier for amplifying a signal for further use in other test equipment.

ELECTRON TUBE TESTING

Some of the more important factors which affect the life expectancy of an electron tube are: (1) the circuit function for which the tube is used, (2) deterioration of the cathode (emitter) coating, (3) decrease in emission of impregnated emitters in filament-type tubes with age, (4) defective seals which permit air to leak into the envelope and oxidize the emitter surface, and (5) internal short circuits and open circuits caused by vibration and excessive voltage. If the average receiving tube is not overdriven, nor operated continuously at maximum rating, it can be expected to have a life of at least 2,000 hours before the filament opens. Because of the attendant expansion (and contraction) of the tube elements during the process of heating (and cooling) the electrodes may lean or sag, causing excessive noise or microphonics to develop. Other electron-tube defects are cathode-to-heater leakage and nonuniform electron emission of the cathode. Tube defects, of which only the most common are listed above, contribute to about 50 percent of all equipment failures. For this reason it is good practice for the technician, when he is troubleshooting equipment, to eliminate immediately any tube known to be faulty; avoiding, however, blind replacement of good tubes by fresh spares. Visible evidence of a tube defect is present when the filament is open (glass-envelope tubes), when the plate current is excessive, when the tube becomes soft (gassy), or when arcing occurs between electrodes. Metal-encased tubes can be felt to determine whether the heater is operating. A tube may be tapped sharply while operating in a particular circuit to provide an aural indication of loose elements or microphonics.

1.315X
Figure 8-10.—The HP-400D, Vacuum Tube Voltmeter.

1.316X
Figure 8-11.—The HP-410B Vacuum Tube Voltmeter.

BASIC ANALYSIS OF TUBE TESTING

In the following discussion three basic types of tube tests will be covered: the substitution test, the emission test, and the transconductance test. Additional tests which are usually incorporated in field-type tube testers will also be discussed. These tests are: the gas test, the short-circuit and noise test, the cathode leakage test, and the filament activity test.

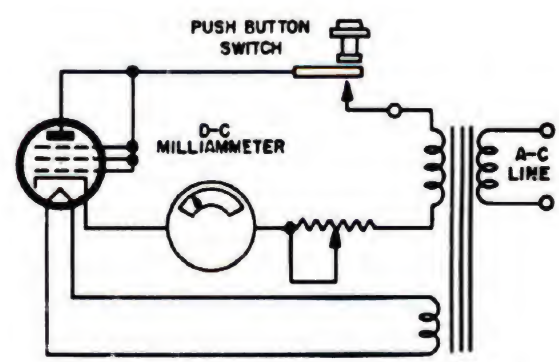
The Substitution Test

Substitution of a tube known to be in good condition is a simple method of determining the quality of a questionable tube. However, in high-frequency circuits tube substitution should be carried out carefully one at a time, so that the effect of differences in interelectrode capacitances of the substituted tubes on tuned (aligned) circuits can be noted. The substitution method of testing cannot be used to advantage to locate more than one faulty tube in a single circuit. If both an r-f amplifier tube and an i-f amplifier tube are defective in a receiver, replacing either one does not correct the trouble. If all the tubes are replaced, there is no way of knowing which tubes were defective. Under these or similar conditions the use of a test equipment designed for testing the quality of a tube saves valuable time.

The Emission Test

An important indication of the condition of a tube is obtained by a comparative check of the cathode (or filament) emission, because in most cases a pronounced lower-than-normal emission, or a complete loss of emission, indicates that the tube has reached the end of its useful life. Both multigrid and diode tubes are tested for cathode emission.

TESTING MULTIGRID TUBES.—For a test of the emission of a multigrid tube, the tube is connected as a half-wave rectifier as shown in figure 8-12. The plate and all the grids of the tube are connected together, a current meter and variable resistor are placed in series with the tube, and the entire circuit is connected across a transformer secondary. Because of their common connection, the plate and all of the grids are at the same time potential with respect to the cathode. As a result, the tube functions as a diode rectifier, conducting current only on the alternate half-cycles when the plate and grids are positive with respect to the cathode. The amount of current that flows indicates the condition of the cathode emitting surface. On tube-testing equipments the meter scale is usually calibrated by dividing the total pointer arc into three areas, which are labeled GOOD, WEAK, (or FAIR), and BAD.



1.73
Figure 8-12.—Basic Circuit used for Emission Test.

TESTING DIODE TUBES.—The emission test for diode (and rectifier) tubes and the diode part of multisection tubes is similar to the emission test used for multigrid tubes. The tube filament or heater is operated at the rated value, and an a-c voltage is applied to the test circuit consisting of the diode, a d-c milliammeter, and a variable resistor. A tapped secondary is utilized in some circuits to control the voltage applied to the tube under test. The variable resistor limits the tube current to a safe value. The amount of current flowing through the resistance and the meter depends on the electron emission within the tube, and therefore indicates the emission quality of the tube.

The Transconductance Test

The term transconductance (also called mutual conductance) expresses the effect of grid voltage upon the plate current of a tube. By measuring the transconductance of a tube it is possible to evaluate the condition of the tube much more accurately than by measuring its cathode emission, because this test more closely approximates actual circuit conditions. Transconductance is expressed mathematically as the ratio of a change in plate current to a change (small) in control-grid voltage with all other electrode voltages held constant. Transconductance is measured in units of conductance called micromhos. The equation for transconductance is:

$$G_m = \frac{\Delta I_p}{\Delta E_g}$$

where G_m is the transconductance in micromhos, ΔI_p is the change in plate current in microamperes, and ΔE_g is the change in control-grid voltage. When the control-grid voltage changes 1 volt (positive or negative), the current change in microamperes is equal to the transconductance in micromhos. In other words, if an amplifier tube has a transconductance of 2000 micromhos, a 1-volt change in the control-grid voltage will cause a plate-current change of 2000 microamperes. The transconductance of a tube may be measured by two methods: one method is the static (d-c) method and the other is the dynamic (a-c) method.

THE STATIC METHOD.—In the static method (also called the "grid shift" method) of measuring transconductance, the d-c bias voltage on the control-grid of the tube under test is changed, and the resultant change in the steady plate current is measured with a current meter. The test circuit is shown in part (A) of figure 8-13. With switch S set to position 1, a negative bias voltage is applied to the control grid of the tube and causes a certain value of plate current to flow. When switch S is thrown to position 2, the control-grid voltage becomes less negative, and the plate current increases to a new value. If the control-grid voltage is varied by 1 volt, the transconductance is the difference (in microamperes) between the initial plate-current reading and the new value of plate current. When such a circuit is used to test various types of tubes, the voltages applied to the electrodes must be made adjustable, so that the correct operating conditions for each tube type may be attained.

THE DYNAMIC METHOD.—The dynamic method of determining transconductance makes use of a circuit which applies an a-c signal

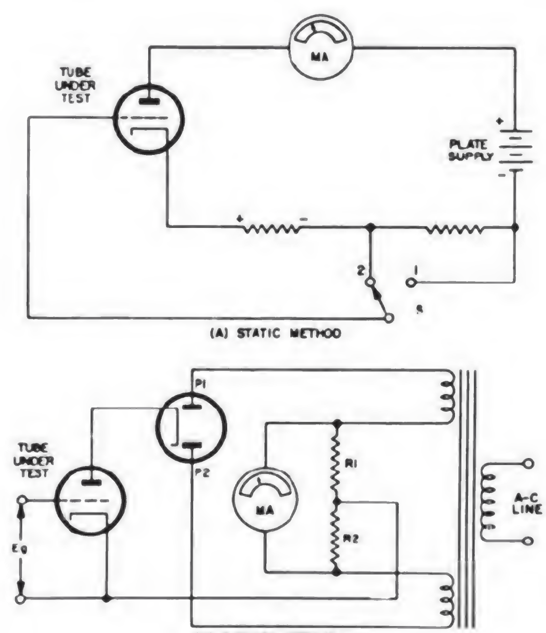


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Figure 8-13.—Basic Circuits used for Transconductance Test.

to the control grid of the tube under test, in addition to a fixed (operating) control-grid bias. The basic circuit is shown in part (B) of figure 8-13. The tube under test serves as the load for the rectifier circuit. The d-c milliammeter is connected across a center-tapped resistor, the upper and lower parts of which are designated as R1 and R2. The meter and resistor combination is placed in series with two secondary windings of the a-c line-voltage transformer. With a fixed value of bias voltage (E_g) applied to the control grid of the tube under test, the circuit operates as a simple full-wave rectifier. On the half-cycle of the a-c voltage when plate P1 of the double diode is positive, there is a current flow through R1, and the force exerted on the meter pointer attempts to deflect it in one direction. When the a-c voltage reverses and plate P2 is positive, the current flows through R2, and the force exerted on the meter pointer is equal and opposite to the previous force. Since these alternations occur at a rather rapid rate (60-cycle line voltage), the resultant force exerted on the meter pointer is zero; consequently, it remains stationary in the zero position.

While the fixed d-c bias voltage is still maintained, an a-c voltage from a secondary of the line-voltage transformer is applied to the control grid of the tube under test. If this applied voltage swings positive at the same time that P1 is positive, the plate current of the triode increases (plate-cathode resistance decreases). Since P1 is positive and conducting, current flows through R1, increasing the deflecting force on the meter pointer in one direction. When the a-c voltage applied to the control grid swings negative, the control grid becomes more negative, decreasing the tube current (plate-cathode resistance increases). With P2 now positive and conducting, the current through R2 decreases, and as a result the deflecting force on the meter pointer on this half of the a-c cycle is not sufficient to cancel the force exerted during the previous half-cycle. Hence, the meter deflection is unidirectional, and is proportional to the difference of the currents in R1 and R2 resulting from the application of the a-c voltage to the grid of the triode. Therefore, the meter reading indicates the change in plate current produced by a change in grid voltage under dynamic conditions. For tube-testing purposes, this increase in plate current is used to indicate the transconductance of a tube under test. Any pronounced deviation from the rated, or normal, transconductance for a specific tube indicates either a defective or an ineffective tube. The meter can be calibrated in terms of good, fair, and bad, or in micromhos.

Additional Tests

The emission tube tester and the transconductance tube tester, which are the two common types of tube-testing equipments employed in the field, may also incorporate circuits for making the following tests: short circuit and noise test, gas test, cathode leakage test, and filament activity test. These tests will be explained in the following paragraphs.

THE SHORT CIRCUIT AND NOISE TEST.—It is very important that the technician apply the test for short-circuited elements to a tube of doubtful quality before any other tests are made. This procedure protects the meter (or any other indicator) from damage. Also it follows logically that, if a tube under test has elements which are short-circuited, there is no further need to apply additional tests to that tube. Short-circuit tests are usually sensitive enough to indicate leakage resistance less than about 1/4 megohm. The proper heater voltage is applied so that any tube elements which might short as a result of the heating process will be detected. The short-circuit test is similar to the test used to detect noisy (microphonic) or loose elements. Since the only difference between the two tests is in the sensitivity of the device used as an indicator, the noise test will be discussed as part of the short-circuit test.

Figure 8-14 shows a basic circuit used for detecting shorted elements within a tube. With

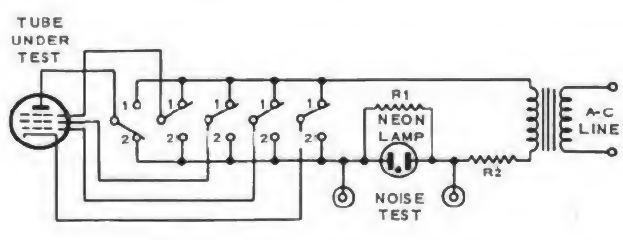

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Figure 8-14.—Basic circuit used for short-circuit and noise tests.

the switch set to position 2 as shown, the plate of the tube under test is connected to the leg of the transformer secondary containing the neon lamp. All the other elements are connected through switches to the other leg of the secondary. If the plate element of the tube is touching any other element within the tube, the a-c circuit of the secondary is completed and as a result both plates of the neon lamp glow. If no short exists, only one plate of the neon lamp will glow. Each of the other elements is tested by means of the switching arrangement shown. Resistor R2 limits the current through the neon lamp to a safe value. Resistor R1 bypasses any small alternating currents in the circuit which might be caused by stray capacitance and thus prevents the neon lamp from indicating erroneously. Tapping the tube lightly is recommended to detect loose elements which might touch when the tube is vibrated.

The noise test is in effect nothing more than a very sensitive short-circuit test. In figure 8-14 two leads are taken from either side of the neon lamp and brought to external receptacles which are labeled noise test. A high-gain amplifier (with speaker) is connected to these receptacles. Perhaps the handiest amplifier for this test is an ordinary radio receiver. The antenna and ground terminals of the receiver are connected to the noise test jacks, and a normal short-circuit test is made while tapping the tube. If tube elements are loose—perhaps not loose enough to indicate on the neon lamp—loud crashes of noise (or static) will be heard from the receiver over and above the normal amount of noise that is present. The noise test may also be made without the use of the high-gain amplifier merely by inserting the leads from a pair of headphones into the noise test receptacles. The latter check, of course, is not as sensitive as the test made with the amplifier, but is generally more sensitive than the short-circuit test made with the neon lamp as an indicator.

THE GAS TEST.—In all electron tubes except some types of rectifier tubes the presence of any appreciable amount of gas is extremely undesirable. When gas is present, the electrons emitted by the cathode collide with the molecules of gas. As a result of these collisions, electrons (secondarily emitted) are dislodged from the gas molecules, and positive gas ions are formed. These ions are attracted by (and cluster around) the control grid of the tube, because it is negative (bias) and absorbs electrons from the grid circuit in order to revert to the more stable gas molecules (not ionized). If the amount of gas in the tube is appreciable, the collisions between the numerous gas molecules and the cathode-emitted electrons release many secondarily emitted electrons, and the resulting flow of grid current is high. The basic circuit used for the gas test is shown in figure 8-15. With switch S set to position 1, a certain value of plate current is measured by the d-c milliammeter. If there is no gas (or a negligible amount) present in the tube, throwing switch S to position 2 does not change the plate-current reading. If gas is present, current flows through the grid resistor (large value), causing a voltage drop to develop with the polarity as shown. The net effect is to reduce the negative bias voltage on the grid of the tube resulting in an increase of plate current. Small plate-current increases are normal; large increases indicate excessive gas.

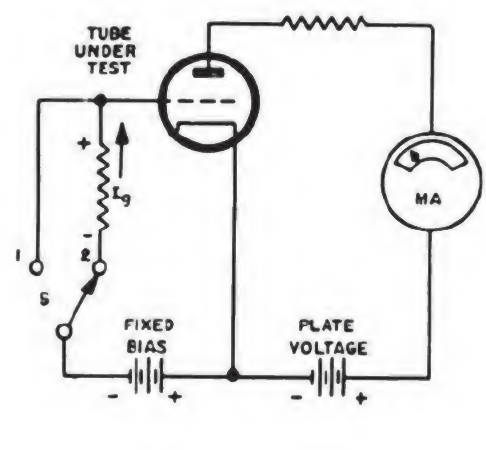

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Figure 8-15.—Basic circuit used for gas test.

THE CATHODE LEAKAGE TEST.—The cathode element of an electron tube is essential because it supplies the electrons necessary for tube operation. Electrons are released from the cathode by means of some form of energy—generally heat—which is applied to it. An indirectly heated cathode consists of a heater wire (usually a tungsten alloy) enclosed in,

but insulated from, a metal sleeve (nickel). This sleeve is coated with an electron emitting material (usually strontium or barium compounds) on its outer surface, and is heated by radiation and conduction from the heater. Useful emission does not take place from the heater wire.

When a tube which uses an indirectly heated cathode develops noise, it is almost a certain indication that a leakage path is present between the cathode sleeve and the heater wire. This assumption is justified because in the design of a tube the heater must be placed as close as possible to the cathode so that maximum tube efficiency is attained. Continual heating and cooling of the tube structure may cause small amounts of the insulation between the cathode and heater to become brittle or deteriorate, leaving a high resistance leakage path between these elements. Under extreme conditions the insulation may shift enough to allow actual contact of the elements. Since the heater and cathode are seldom at the same potential, any form of leakage causes noise to develop in the tube. The cathode normally is maintained at a higher positive potential, because cathode bias is the most common type of bias utilized. The heater circuit is usually grounded to chassis, either on one side of the filament supply or by a center-tap arrangement. Therefore, if a resistance path is present, a leakage current may flow from the heater to the cathode. Thus, in effect the cathode functions in the same manner as the plate of a tube; that is, it receives electrons. Assuming the existence of a high-resistance short, the current flow from the heater to the cathode will vary with any vibration of the tube because vibration varies the amount of resistance. If the cathode and heater are completely shorted (zero ohms), it is impossible for the tube to develop any cathode bias.

A cathode leakage test is sometimes made while a tube is being tested for short-circuited elements or noise. However, some tube-testing instruments incorporate the cathode leakage test as an additional test which is not part of the short-circuit test. Figure 8-16 shows a basic circuit which is used to detect leakage between the heater and cathode elements of a tube. With switch S set to position 2, a certain value of plate current flows. When switch S is thrown to position 1, the cathode becomes a floating element; if no leakage path is present, the plate current should fall to zero. If the elements are completely shorted, the plate

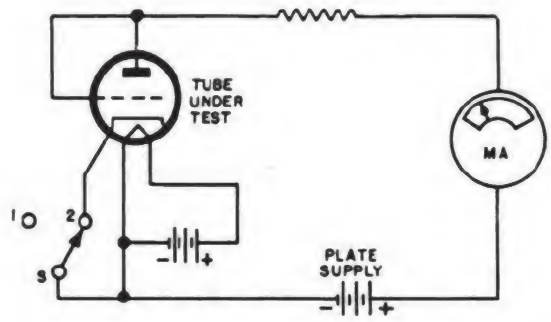

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Figure 8-16.—Basic circuit used for cathode leakage test.

current reading remains the same as the initial reading (switch S in position 2); if they are only partially shorted, a plate current less than normal but greater than zero is indicated.

THE FILAMENT ACTIVITY TEST.—The filament activity test is used to determine the approximate remaining life of an electron tube insofar as the longevity of the cathode emitter is concerned. The test is based on the principle that the cathode in almost all electron tubes is so constructed that a decrease of 10 percent of the rated heater voltage causes no appreciable decrease in emission.

On a tube-testing equipment incorporating this test there is a two-position switch (FILAMENT ACTIVITY TEST) which has one position marked NORMAL and the other marked TEST. The switch remains in the NORMAL position for all tests other than the filament activity test. When the switch is set to the TEST position, the filament (or heater) voltage which is applied to the tube under test is reduced by 10 percent.

The filament activity test is performed as follows: After the quality test is made, the TUBE TEST button is held depressed, and the filament activity test switch is set to TEST position. If the indicator shows a decreased reading after a reasonable time is allowed for the cathode to cool the useful life of the tube is nearing its end.

SUPPLEMENTARY ELECTRON TUBE INFORMATION

The following discussion, which is based on material taken from field reports, is presented

to provide the technician with specific information concerning electron tube failures and factors that affect tube life.

Electron Tube Failures

Experience has shown that tube failures may be roughly classified as follows: mechanical defects and gas within tube, filament (or heater) burn-out, change in tube characteristics, physical damage, and intermittent shorts. Mechanical defects and rise of gas pressure within the tubes are attributed to faulty construction and processing. Some of these defects cannot be detected by standard testing methods until the tubes have been in operation for some time. Filament burnout may be caused by repeated sudden application of full voltage to the filament. Initial heating of the filament is nonuniform. As a result, mechanical stresses due to thermal expansion are set up, and these stresses weaken the filament structure and hasten its failure. Change in tube characteristics is a broad classification and covers decreasing emission, change in cut-off voltage, changing transconductance, etc. Such changes are usually the result of deterioration of the cathode structure, or formation or a cathode interface surface in the tube, or changes in alignment of the electrode parts. Physical damage is largely accidental. It includes such causes as breakage, bending of pins, and inadvertent application of excessive voltages. Intermittent shorts are caused mainly by foreign matter, such as lint within the tube assembly.

Electron Tube Life

Tubes that have operated for several hundred or a thousand hours with relatively stable characteristics are more reliable than new tubes just taken out of stock. In general, it is not advisable to replace all the tubes of a group after a predetermined number of hours without regard to their condition. In fact, if the tubes have operated for any appreciable length of time, the intervals between testing may be lengthened. However, certain tubes are notorious for limited operation, and in such cases periodic changing will prevent much trouble.

It has been found that by operating new tubes for 100 to 300 hours in a test rack prior to actual use, 80 percent of the tubes that would have failed early in electronic equipments were eliminated. For pre-operation a steady current may be passed through the tube so that the plate and screen operate between one-half and full rated dissipation. Such pre-operation reveals short-time changes of tube characteristics, improper emission, inherent mechanical defects, gassy conditions, warping or sagging of grid structures, poor welds, and cracked envelopes. Tubes which survive the first 300 hours with only minor changes in characteristics are considered "good risks" for several thousand hours.

Electron tube life can be increased if frequent on-off switching of the filament power is avoided. The inrush current of the cold filaments is many times the rated operating current.

TUBE-TESTING EQUIPMENTS

A number of different types of equipments have been developed for testing the condition of electron tubes. Bridge-type instruments are used in laboratory work for the measurement of three important parameters of grid-controlled electron tubes: namely, amplication factor (u), plate resistance (r_p), and transconductance (G_m). Diode and rectifier characteristics are checked by measuring the plate current resulting from the application of a specified value of plate voltage. These bridge measurements, as well as the calculations which are a necessary part of the complete laboratory tests, are tedious and time-consuming. To be of practical use to the technician in the field, a tube-testing equipment must provide a simple and quick appraisal of the quality of a tube. While using the same basic principles of laboratory checks, tube tests made by field-type tube testers generally employ simplified methods, so that, even though the test results are limited in accuracy, they serve in a practical manner to evaluate the condition of a tube. Tube-testing equipments, however, have certain limitations in that, although they compare tubes to a predetermined standard, they do not reveal how a tube may operate in a circuit under a specified set of conditions. The final, and most accurate, indication of the condition of a tube is its ability to function in a circuit designed for its use. It is seen then that field-type tube testers, although limited because of their relative inaccuracy, are still considered important as an aid to fast troubleshooting since they provide quick appraisals of the condition of electron tubes.

There are two different types of tube-testing equipments in common use in the field at the present time. These equipments, which are distinguished by the tube characteristic tested, are known as the emission type tester and the transconductance type tester.

The Emission Type Tester

The emission tester measures the condition of the cathode emitting surface. The end of the useful life of a tube is usually preceded by a reduction in electron emissivity, that is, the cathode becomes unable to supply the number of electrons necessary for proper tube operation. Also, if the tube has an open element, the defect prevents proper emission, and the tester indicates it as a reject.

The emission type tester has certain limitations and disadvantages. Since the manufacturer of a tube does not state a definite 100 percent emission point which could be used for reference, the emission test is not conclusive. High emission does not necessarily indicate a good tube because this condition might be present in a tube with a faulty grid structure or one which has a highly emissive spot on its cathode. Very high emission has also been observed just before a tube fails completely; hence, fairly low emission does not necessarily indicate in all cases that a tube is near its end-of-life point. A further disadvantage of the emission test is that gas is liberated within the tube when a-c test voltages are applied unless the test is made quickly. Also, because the tube is not operated with its recommended d-c electrode voltages in this test, it is not tested under actual operating conditions. It is also possible for a tube to show normal emission and still not operate properly. The reason for this is that the efficiency of a tube depends on the ability of the grid voltage to control the plate current. The emission type tester tests only the plate current developed; and not the ability of the grid to control the plate current. The transconductance type tester checks the latter characteristic.

The Transconductance Type Tester

The transconductance type of tester provides a more accurate evaluation of the condition of a tube than the emission type tester because it measures the amplification ability of the tube under simulated circuit conditions. The transconductance is measured and then compared with the ratings of the tube manufacturer. The meter scale of this type of tube tester is usually calibrated to indicate the transconductance (G_m) either directly in micromhos or indirectly in terms of good, weak, or bad. A voltage or power amplifier tube is considered defective when its transconductance decreases to 70 percent of the value stated in standard tube tables; the oscillator section of a converter tube is considered defective when its transconductance decreases to 60 percent of table values.

A TYPICAL TUBE TESTER

Electron Tube Test Set TV-10/U (figure 8-17) is a portable tube tester of the dynamic mutual conductance type. The TV-10/U is used to test and measure the performance capabilities and rejection limits of receiving-type and lower-power transmitting-type electron tubes. The test set operates from a power source delivering 105-125 vac at 50-1,000 cps. A block diagram is shown in figure 8-18.

Two adapters are provided to permit the testing of certain tubes with special bases or contacts in the standard OCTAL socket of the test set. Adapter E105 is used to test tubes of type 829 and 832; Adapter E107 is used for tubes of the 2C39 type. Test leads W101 and W102 are provided to connect external plate or grid caps on the tube under test to the panel jacks marked P and G, respectively.

All operating controls, indicators, and test sockets are located on the test set panel. Necessary tube test data is contained in a roll chart mounted beneath the panel for protection. By means of a drive gear, the roll chart can be indexed so that the control settings and rejection limits for the specific tube under test are visible through cut-outs in the panel.

THE OSCILLOSCOPE

The basic operating principles of the cathode-ray oscilloscope are described and the operating controls identified in Basic Electronics, Nav Pers 10087-A.

A knowledge of the proper use of this instrument is one of the most valuable tools that a CT M can have. Therefore the following paragraphs are devoted to the practical aspects of the subject. It should be emphasized that all of the details of the subject cannot be

covered in a few paragraphs of reasonable length. The technician will find additional helpful information in the Handbook of Test Methods and Practices (latest edition), NavShips 91828, and in the instruction books that accompany the test instruments.

The cathode-ray oscilloscope is generally used to permit the technician to observe voltage waveforms in testing electronic circuits. Because voltage waveforms are observed, an ELECTROSTATIC cathode-ray tube (CRT), which employs voltage to deflect the electron beam, is used.

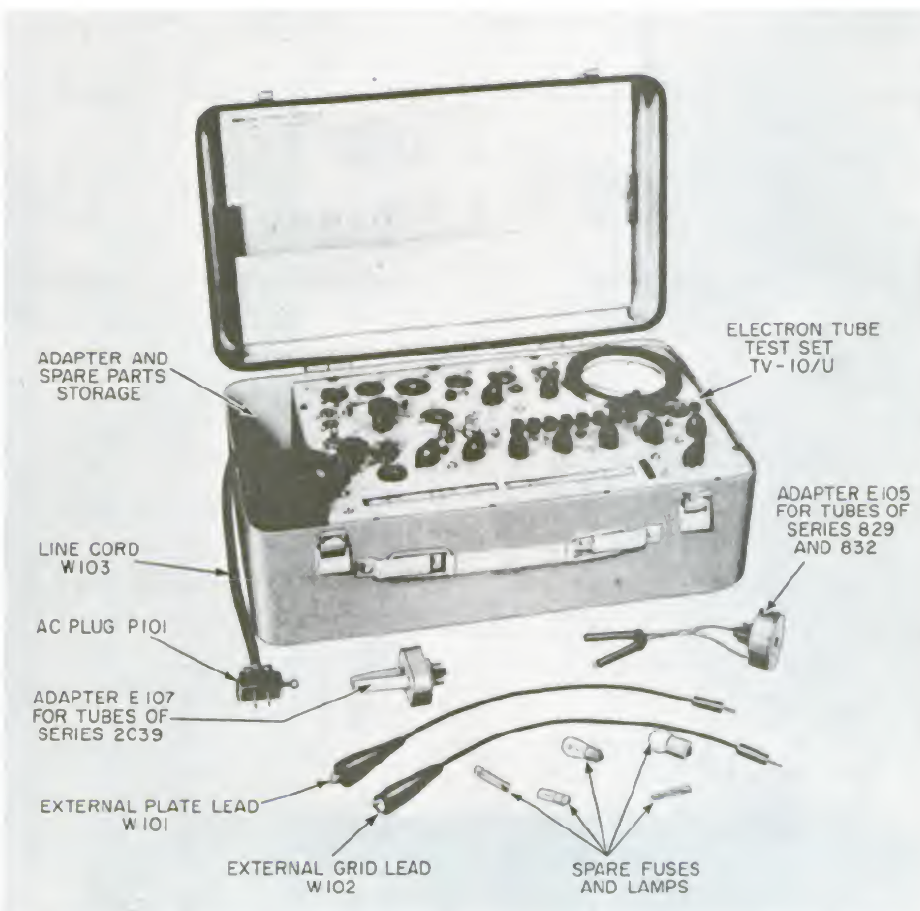

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Figure 8-17. -Electron Tube Test Set TV-10/U.

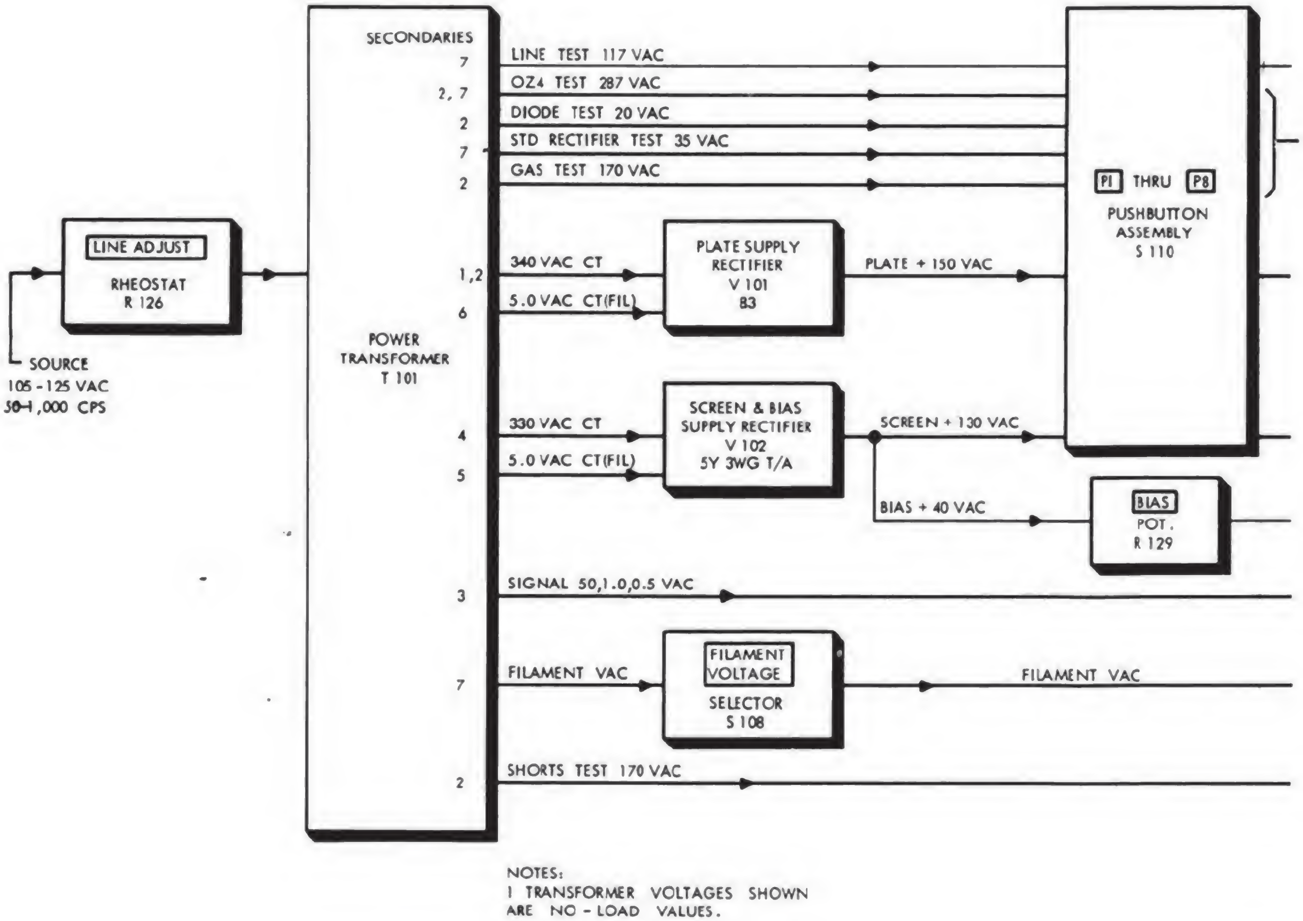

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Figure 8-18.–Electron Tube Test Set TV-10/U, Functional Block Diagram.

Some oscilloscopes may use an Electromagnetic CRT, which employs current to deflect the electron beam. This type of oscilloscope is used for certain applications, other than general testing, where its properties make it more suitable than the electrostatic-deflection type. These special applications involve complex deflections such as for a data viewing screen or for television use where trapezoidal deflection or circular scan are required. Additionally the electromagnetic CRT is more simply constructed, the beam deflection circuits not being built into the tube but in the associated equipment.

In general, test oscilloscopes are used to align and test electronic equipment, to make hum measurements, to make frequency comparisons (to determine an unknown frequency), to observe complex waveforms, and to take percentage modulation measurements.

GENERAL INFORMATION ABOUT OSCILLOSCOPES

To obtain an accurate presentation of the voltage waveform, a few precautions must be observed. The approximate magnitude of the voltages in the circuit under test must be known so that the operator can take steps to safeguard himself from shock and the oscilloscope from a voltage breakdown.

Dependable data can be obtained from the oscilloscope only if its sensitivity and frequency characteristics are known. To make certain that the waveform will not be distorted

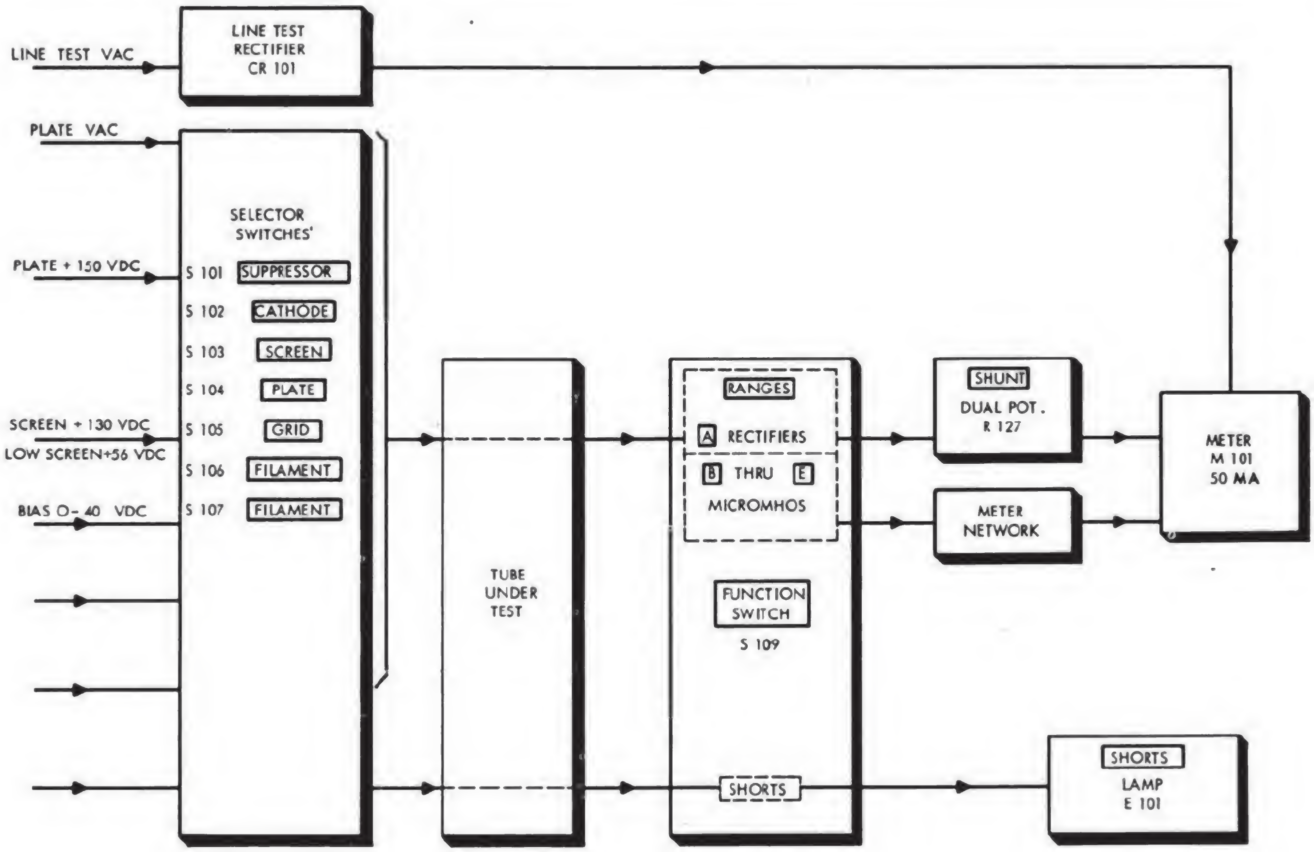

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Figure 8-18.—Electron Tube Test Set TV-10/U, Functional Block Diagram—Continued.

it is essential that the manner in which distortion takes place be understood and that precautions be taken to minimize such distortion.

Input Circuit

The input to most oscilloscopes is between an input terminal (which is above ground potential) and the common ground terminal. The input terminal is almost always coupled to the grid of the amplifier through a capacitor. Seldom do the capacitors used have voltage ratings in excess of 450 volts. Therefore, unless the approximate magnitude of the voltage under test is known, damage to the oscilloscope through breakdown of the input capacitor may result.

Voltage Dividers

In some cases, it may be necessary to observe waveforms in circuits where the voltage is much greater than the components within the oscilloscope can withstand. A voltage divider may be used in such instances to reduce the voltage to a value that will not damage the equipment. In any case, it is very important that the oscilloscope be adequately grounded. Grounding the oscilloscope is a precaution that must be taken for the protection of the operator, because a failure of some part of the voltage divider can raise the potential of the whole oscilloscope to a dangerous level if the oscilloscope case is not solidly connected to ground.

If the voltage divider used is a capacitance divider, a wise precaution is to shunt each capacitor with a high resistance in order to maintain the proper voltage distribution across each capacitor. Two voltage dividers are shown in figure 8-19. In figure 8-19A, the capacitance alone causes the voltage across C2 to be one-tenth of the voltage across C1. However, the leakage resistances, R1 and R2, may be of such values that they divide the voltage by a very different ratio. If the leakage resistance of the capacitors is high with respect to the magnitude of the X_C ohms, the leakage resistance will have negligible effect on the voltage distribution across the capacitors. However, if the leakage resistance is of the same order of magnitude as that of the X_C ohms, the leakage resistance may have a pronounced effect on the distribution of the voltage across the capacitors. This condition might cause excessive voltage across one capacitor and result in a breakdown. To prevent this unbalanced distribution of voltage, resistors R3 and R4 may be added, as in figure 8-19B. Because the leakage resistance of a good capacitor is of the order of 1000 megohms and because R3 and R4 are relatively low in resistance, the two resistors fix the voltage division at the same ratio as do the capacitors, and the voltage divider may be easily designed to withstand the high voltage.

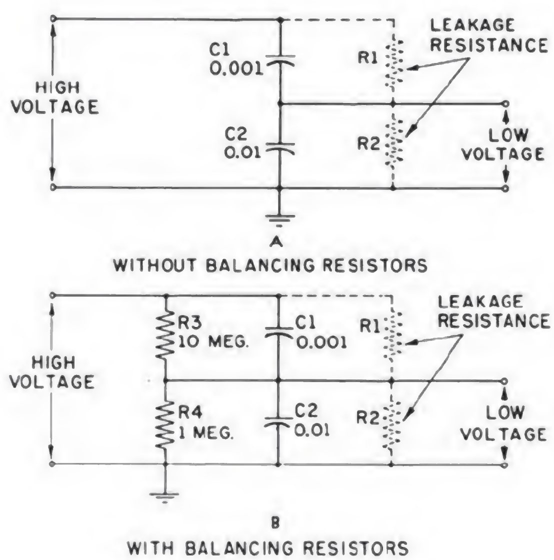

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Figure 8-19.—Capacitance voltage divider.

Frequency Ranges

The range of sweep frequencies in a given oscilloscope is usually indicated on the front panel of the instrument. The frequency range that the vertical and horizontal amplifiers are capable of amplifying properly is given in the manufacturer's instruction book. Generally, only the best oscilloscopes use amplifiers that will amplify voltages whose frequency is below 20 or above 1,000,000 cycles per second. Oscilloscopes that do not cover as wide a range of frequencies as this may be satisfactory for most uses, but distortion is likely to occur when saw-tooth or rectangular waveforms of a high recurrence rate are investigated. Examples of this type of distortion are given in figure 8-20. The input is a "square" wave, which is a rectangular waveform. High performance oscilloscopes are capable of amplifying over a broader frequency range, and, accordingly, may be used on rectangular and saw-tooth waveforms of high recurrence rates without distorting the shape of the waveform.

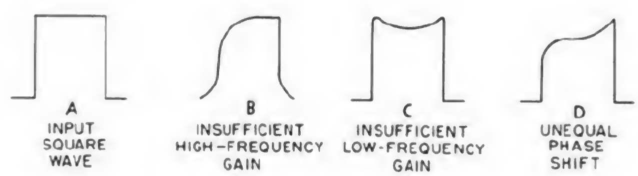

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Figure 8-20.—Distortion of square wave by improper amplification.

Deflection Sensitivity

The deflection sensitivity of an oscilloscope may be defined as the distance in centimeters that the spot is moved on the screen when 1 volt is applied to the deflecting plates. The deflection sensitivity in this case is expressed in centimeters per volt. The most accurate way of measuring this quantity is to apply a known d-c potential directly to the deflecting plates and measure the distance that the spot is moved by this voltage. The number of centimeters that the spot moves, divided by the voltage applied, is the deflection sensitivity in centimeters per volt.

The deflection sensitivity (or factor) may also be expressed as the input voltage to the amplifier (horizontal or vertical) for a deflection of 1 inch of the spot on the CRT screen. In this case, the amplifier gain control is adjusted to a suitable value that is arbitrary (for example, midscale). The magnitude of the input sine-wave voltage is measured with an accurate a-c voltmeter. Most a-c voltmeters indicate the root-mean-square (rms) value of voltage. However, the deflection of the spot on the screen is proportional to the amplitude of the sine wave from the positive peak to the negative peak (peak-to-peak voltage). To convert the rms voltage at the input to peak-to-peak voltage, the input meter reading must be multiplied by 2.828.

Thus, the effective sensitivity (gain) of the oscilloscope is volts per inch is the peak-to-peak voltage applied at the input of the amplifier divided by the peak-to-peak amplitude of the trace in inches. For example, if the peak-to-peak voltage applied to the vertical amplifier is 2.8 millivolts and the peak-to-peak amplitude of the trace is 2.8 inches, the vertical deflection sensitivity will be $\frac{0.0028}{2.8} = 0.001$ volt per inch. If the gain control is changed, the effective sensitivity will also change. However, the sensitivity of the CRT itself is not affected by the use of the amplifier. The only factor changed, when changing the gain control, is the amplitude of the voltage applied to the deflecting plates.

If the peak-to-peak voltage applied directly to the vertical deflection plates without going through the amplifier is 48 volts and the peak-to-peak amplitude of the trace is 1 inch, the vertical direct deflection sensitivity will be 48 volts per inch.

Stray Pickup

To avoid pickup of stray signals, the leads from the circuit under test to the oscilloscope should be as short as possible. If the leads are long, a greater voltage can be induced in them by stray fields than would be induced if the leads were short. The pickup may be so disturbing in some cases that it will be almost impossible to use the oscilloscope. A few things can be done to reduce the effect that stray fields have on the oscilloscope.

First, the cathode-ray tube must be very carefully shielded from all stray fields. In most cases, this shielding is provided by the Aquadag coating on the inside of the tube, by a metallic shield outside the tube, and by the oscilloscope case.

Second, the common side of the oscilloscope circuit should be connected to a ground point in the circuit under test and to a good external ground connection. This connection will aid in eliminating most of the stray voltages that are picked up by the leads.

Third, a low-capacitance coaxial cable may be used to reduce still more the effect of stray fields.

Distortion

Several sources of distortion are possible in the production of CRT display. Although distortion can be eliminated by simple precautions in some cases, it is very difficult to eliminate in other cases. A summary of some of the major factors to be considered follows.

1. Perhaps the most obvious component in which distortion can enter is the deflection amplifier. It is important, therefore, to know the frequency response of the amplifier being used. An estimate may then be made of the possibility of distortion for a given signal.
2. If the sweep is nonlinear, the shape of the wave on the screen will not be a true picture of the voltage under test. However, if the oscilloscope is not defective, the sweep will generally be linear enough for most purposes.
3. When signals of relatively high frequency are to be observed, the time of fly-back may become an appreciable fraction of the period of the signal. To avoid distortion of this type, it is well to adjust the sweep frequency so that several cycles of the signal will appear on the screen.
4. If the magnitude of the synchronizing voltage is too great, the image may be distorted because the sweep is terminated too soon. This condition may be avoided most simply by setting the synchronization control at zero while the sweep frequency is adjusted. When the sweep frequency is some integral multiple of the signal frequency, the image will be stationary on the screen. The synchronizing voltage should then be turned up just enough to stop the apparent motion of the image on the screen.
5. In general, the input impedance of the oscilloscope will be much higher than the impedance of the circuit at the point where the

test is to be made. Therefore, the input impedance of the oscilloscope will not change appreciably the circuit load nor the voltage at the connection point, and a true picture of the voltage may be observed. In some circuits, however, the impedance may be very high (perhaps up to 100 megohms), and the input impedance of the oscilloscope may load the circuit and change the voltage so radically that it will be difficult to obtain a true picture.

6. The input shunting capacitance of an oscilloscope is generally small (of the order of 20 to 60 $\mu\mu f$), but it may be sufficient to alter the characteristics of a video amplifier or the tuning of a high-frequency oscillator.

7. When one specific type of equipment is to be maintained, many of the preceding sources of distortion may become of academic interest only. When, for example, the same oscilloscope is used with the same pair of leads to check repeatedly a given set of waveforms, the distortion will always be the same if the circuits are operating properly. If the waveforms through the system are recorded when the system is working properly, the maintenance testing need consist only of a comparison of the waveforms obtained with the recorded standard waveforms. In such a case, it is not necessary to eliminate all distortion, because the test will consist of a comparison of two sets of data that are distorted in the same way. It is desirable, however, to eliminate distortion as much as possible in order that the operation of the circuit under test may be better understood. However, successful testing may be performed regardless of distortion, if the same test equipment is used in the same way in every check.

USE OF THE OSCILLOSCOPE FOR SIGNAL TRACING

Sine Waveform

The cathode-ray oscilloscope (CRO) is used chiefly for checking the waveform of the signal voltage in electronics circuits. The most commonly found waveform in a-c power circuits is the sine wave. Most cathode-ray oscilloscopes have a line-test signal binding post internally connected to a low-voltage winding of the powersupply transformer so that an a-c voltage at powerline frequency (60 cycles) is available to the operator for testing purpose. A jumper may be connected between the line test signal binding post and the a-c Y input. If the sweep range is set on the line between 15 and 75 and the sweep vernier is adjusted to 60, a single cycle of sine waveform will appear on the cathode-ray screen. This pattern may be used for comparison with other sine waveforms.

Other Waveforms

In general, the method of obtaining the signal waveform is to adjust the horizontal sweep frequency to approximately the frequency of the signal voltage to be presented on the screen and then to apply the signal voltage to the Y input binding post, making sure that the ground terminal is returned to the ground on the equipment from which the test voltage is derived. The horizontal gain control is then adjusted for full horizontal deflection and the vertical gain control adjusted for slightly less than full scale deflection. If the pattern is not properly centered on the screen, the horizontal and vertical positioning controls should be adjusted until the desired centering is obtained.

The CRO is used in signal tracing to determine the location of a fault. The signal voltage is derived from various test points (for example, in the circuit shown in figure 8-21) and the pattern compared with the pattern for each particular check point, as indicated in the figure. The bandwidth and the sweep frequency of test CRO are indicated for specified conditions of equipment operation. For example, at test point TP107 in the top center of figure 8-21, the sweep frequency (SF) of the test oscilloscope is designated as 60 cycles; the duration of the zero voltage condition is 15,000 μs (T'), and the length of the negativegoing pulse (-100 v) is 1670 μs (T). The letter, R, designates the range setting of the equipment. The illustration represents a portion of the servicing block diagram of the Range-Azimuth Indicator AN/SPA-4A.

THE OSCILLOSCOPE AS A MEASURING DEVICE

D-C Voltmeter

The electrostatic CRT is a voltage operated device. The amount of deflection of the spot is proportional to the magnitude of the voltage applied to the deflecting plates. If the deflection sensitivity of the CRT is known, the oscilloscope

can be used as a voltmeter on either direct or alternating voltages. The oscilloscope has the advantage of having extremely high input impedance when the voltage to be measured is applied directly to the deflecting plates. However, because both the range of voltage measurements and the accuracy of indication are less than that available in commercial d-c voltmeters, the oscilloscope is not widely used for the measurement of d-c voltages.

A-C Voltmeter

The CRO is a better device for measuring alternating voltages than most conventional a-c voltmeters. The principal difficulty with the oscilloscope is the calibration of its deflection sensitivity. If this factor can be determined accurately, the magnitude of the alternating voltage can be determined very simply. The advantages of the oscilloscope as an a-c

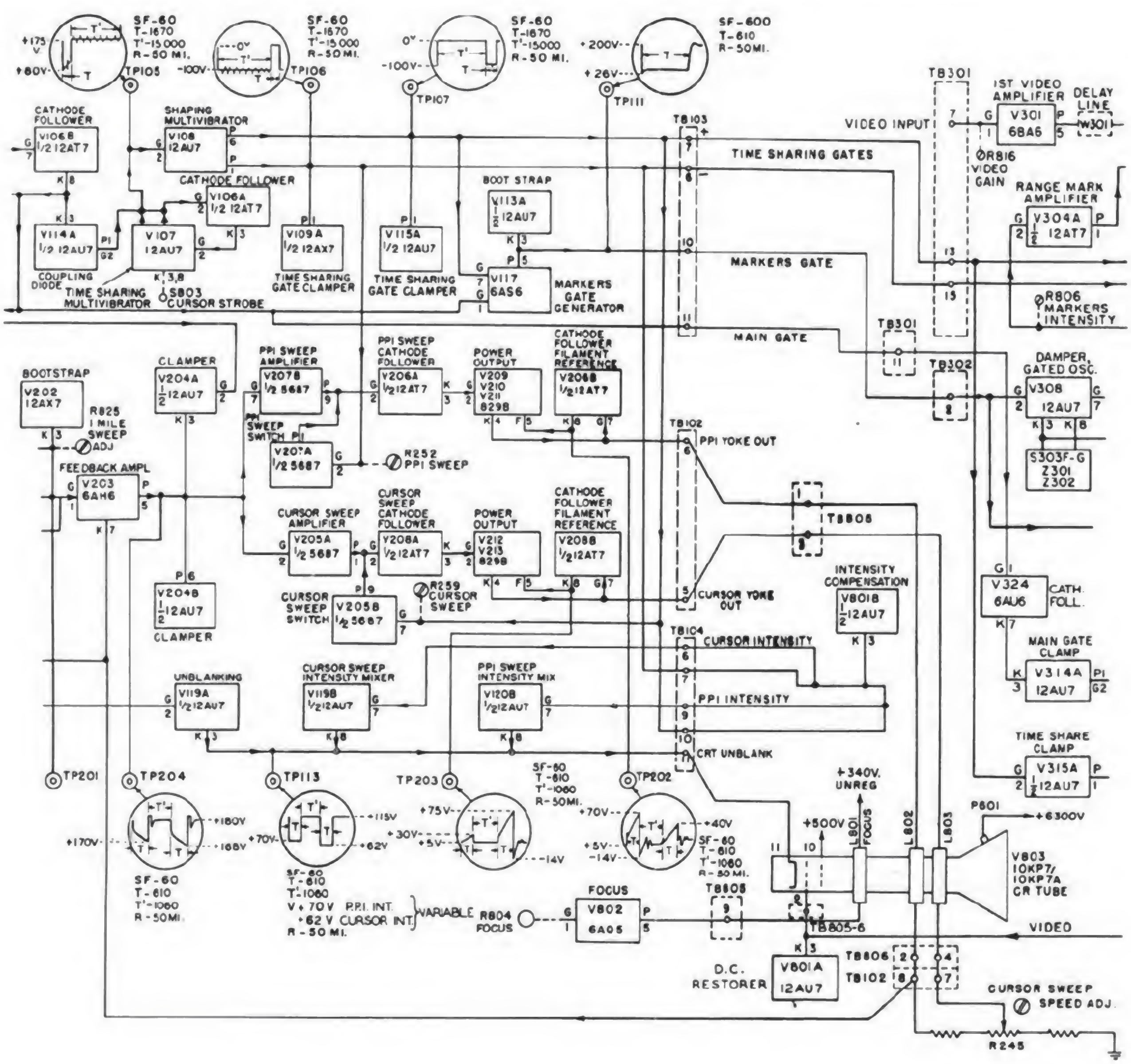

Figure 8-21.—Signal tracing with the CRO.

voltmeter are its very high input impedance, its ability to measure equally well voltages of a wide frequency range, and its ability to indicate magnitude, regardless of waveform.

The oscilloscope shows the peak value of the applied a-c voltage; whereas, standard a-c meters show the rms values of the sine-wave, a-c voltage. Peak values may be readily converted to rms values, but the results may be misleading for voltages whose waveforms are other than sinusoidal.

Ammeter

The electromagnetic CRT is a current operated device. Accordingly, it could be used to measure current magnitudes directly if it were properly calibrated. This type of tube, however, is rarely used in test oscilloscopes. The electrostatic CRT, as mentioned previously, is widely used in test oscilloscopes, and it may be used to measure currents indirectly. If the current to be measured is passed through a calibrated resistor, the resulting voltage across the resistor may be indicated on the oscilloscope screen. By application of Ohm's law, the current may be calculated; that is, R is known, E is measured, and I can be calculated by the equation,

$$I = \frac{E}{R}$$

Wattmeter

The same method that is used to measure current can also be employed to measure power. The power dissipated in a resistor is equal to the product of the current through the resistor and the voltage across it. Therefore, the power dissipated in the resistor may be expressed as

$$P = EI = \frac{E^2}{R}.$$

If the voltage measured by means of the oscilloscope is substituted in this equation, the power may be calculated (if the resistance is known).

LISSAJOUS FIGURES

A Lissajous figure is a pattern created on an oscilloscope screen when sine-wave voltages (usually of differing frequencies) are applied simultaneously to both the horizontal and vertical deflecting plates. One of the principal uses of Lissajous figures is to determine an unknown frequency by comparing it with a known frequency.

Development of Simple Figures

The development of four types of Lissajous figures is shown in figure 8-22. Each Lissajous figure is developed by plotting a smooth curve through points formed by the intersection of horizontal and vertical lines projected from corresponding points on two sine curves (bottom and right side of Lissajous figures). Adjacent points on the sine curves at the right are separated by equal intervals (30°). Those on the sine curve at the bottom are separated by an interval of 15°. The ratio (horizontal to vertical) of the frequencies applied to the two pairs of deflecting plates is 1:2; that is, in this figure the frequency on the horizontal deflecting plates is one-half the frequency on the vertical deflecting plates. It does not matter what the actual frequencies are, as long as one of the frequencies is known.

If the two voltages are in phase; that is, if both voltages are passing through zero and going positive at the same instant a figure eight pattern will be traced (fig. 8-22A). As the phase changes slightly, the pattern will change, as shown in figure 8-22, B, C, and D. When the phase angle is 90°, the loops will close, as in figure 8-22C. If the phase angle is greater than 180°, the pattern will be inverted, as in figure 8-22D.

Interpretation of Patterns

One feature that all of these images have in common is that the pattern touches the horizontal lines (xx or x'x' of figure 8-22A) at two points. This is true of the remaining patterns of the figure, even for the line tangent to the top of figure 8-22C, because the trace passes point 1 on the figure twice during each cycle. Likewise, the vertical lines (yy or y'y' of fig. 8-22A) are touched by the pattern at only one point. The ratio of the number of points of tangency is equal to the ratio of the two frequencies. Expressed as an equation,

$$\frac{f_h}{f_v} = \frac{\text{number of tangent points on vertical line}}{\text{number of tangent points on horizontal line}}$$

where f_h is the frequency of the signal applied to the horizontal deflecting plates and f_v is the

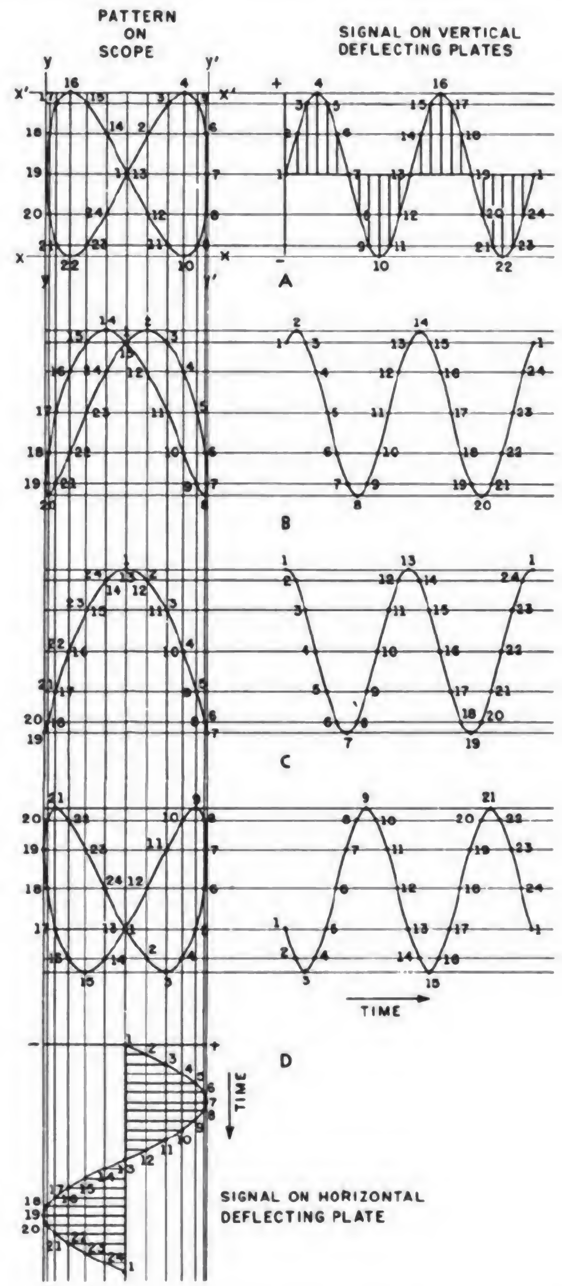

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Figure 8-22.—Lissajous figures for a 1:2 horizontal to vertical input frequency ratio.

frequency of the signal applied to the vertical deflecting plates.

The number of tangent points on the horizontal and vertical lines is most easily counted when the Lissajous figure is stable (not moving) and when it is symmetrical as in figure 8-22A. In this figure the ratio of the number of points of tangency on the vertical line to the number on the horizontal line is 1:2. If f_V = 120 cycles,

$$f_h = f_v \frac{\text{number of tangent points on vertical line}}{\text{number of tangent points on horizontal line}} = 120 \times 1/2 = \text{cycles.}$$

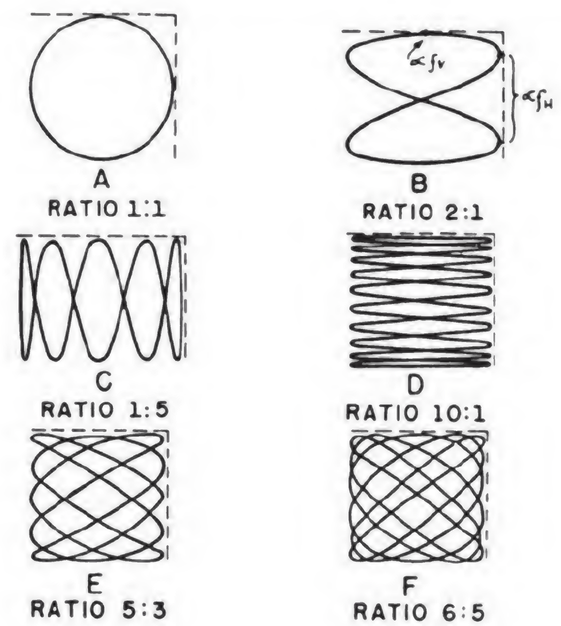

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Figure 8-23.—Lissajous figures for various frequency ratios.

Miscellaneous Figures

In figure 8-23, several varieties of Lissajous figures are shown. The ratio (horizontal to vertical) of the two input frequencies is indicated in each case. Unless the oscilloscope screen is very large, ratios higher than 10:1 are difficult to interpret. The circle shown in figure 8-23A, is the simplest type of Lissajous figure. The pattern in figure 8-23B is for a 2:1 ratio. Compare this with the pattern shown in figure 8-22A, in which the ratio is 1:2.

Figure 8-23, C through F, indicates the increasing complexity that is encountered in ratios of higher order.

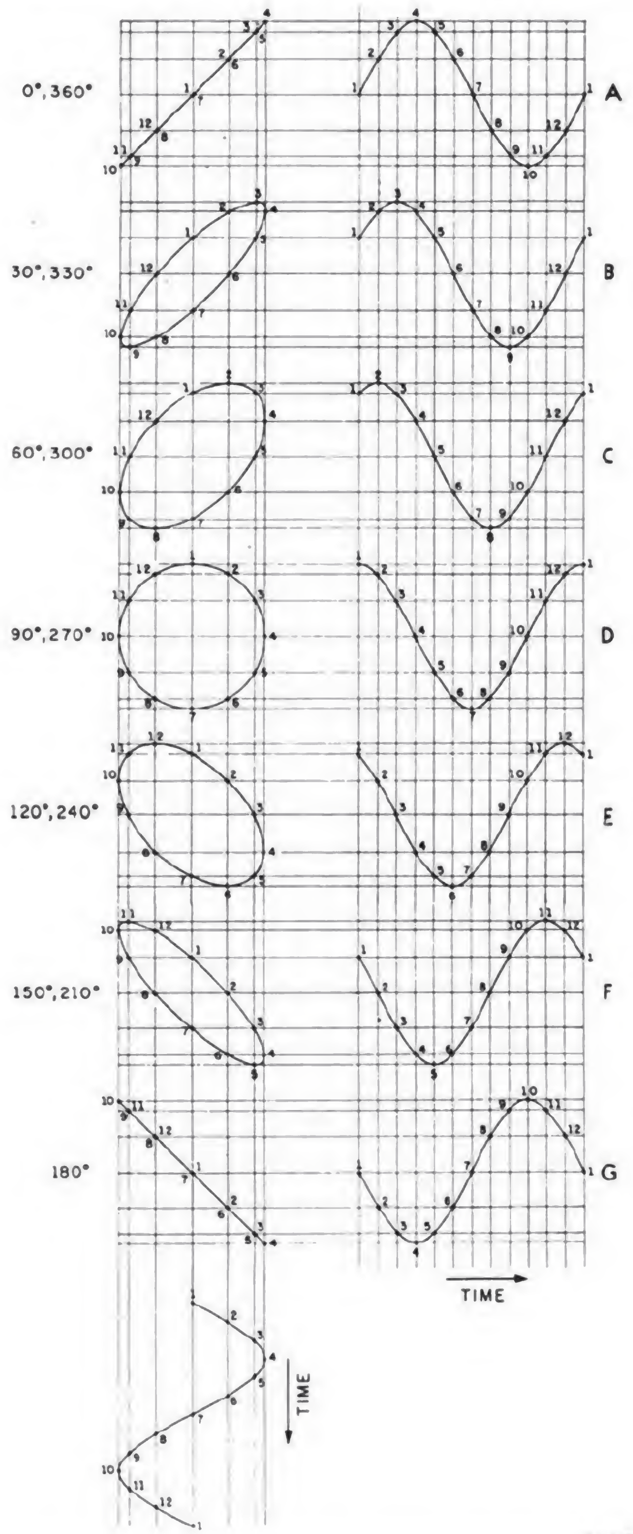

Figure 8-24.—Lissajous figures that indicate phase difference.

Indication of Phase

The patterns of figure 8-24 are formed by applying to the deflecting plates sine-wave voltages having the same frequency and amplitude, but having various phase differences. It can be seen in figure 8-24A, that the resultant trace is a line at a 45° angle when the voltages are exactly in phase (0° or 360°). As the phase angle is made greater, the straight line opens into a broadening ellipse, as in figure 8-24B and C. When the phase difference is 90°, the ellipse becomes a circle, as in figure 8-24D. As the phase difference is increased beyond 90° (fig. 8-24, E through G), the circle begins to collapse toward another straight line, but this time the line is at 135° when the voltages are out of phase by 180°.

The patterns shown in figure 8-24 can be obtained only if the amplitude of the voltage applied to the vertical deflecting plates is the same as the amplitude of the voltage applied to the horizontal deflecting plates. If one voltage is greater than the other, the pattern will never become circular, but will always be elliptical. Therefore, if such patterns are to be used to measure the phase difference between two sine-wave voltages, care must be taken to ensure that both voltages are of the same amplitude, so that the screen can be calibrated.

MODULATION MEASUREMENTS

Amplitude modulation measurements are made by the observation of one of two basic modulation patterns—the wave-envelope or the trapezoidal pattern—either of which gives a continuous, direct picture of the modulated output of the transmitter.

The wave envelope pattern gives a direct indication of the shape of the modulation envelope, as indicated in figure 8-25A. A small pickup loop is coupled inductively to the final tank circuit of the transmitter and connected directly to the vertical deflection plates. The CRO saw-tooth generator is used to provide the horizontal sweep frequency.

When an audio signal generator is used in place of the microphone voice input, a voltage of sine waveform is supplied to the modulator, and the pattern on the CRT is easily stabilized by applying a portion of the audio voltage to the

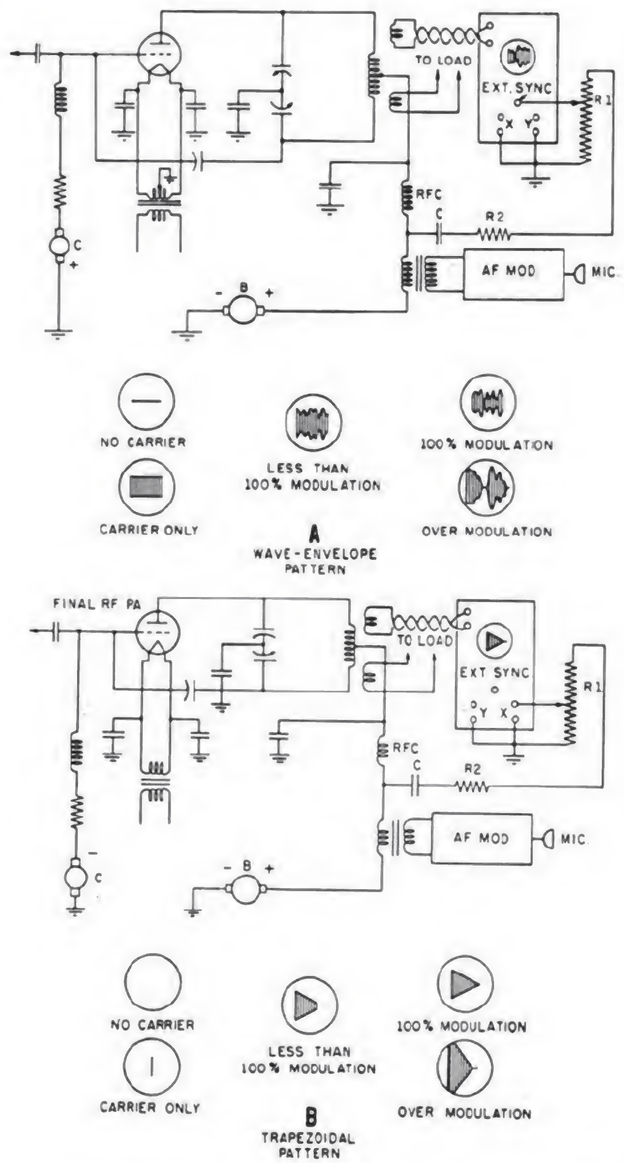

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Figure 8-25.—Modulation measurements.

external sync terminal of the oscilloscope. The audio voltage is obtained from the voltage divider composed of R1, R2, and C. Capacitor C blocks the d-c component and couples the a-f component to the sync input. The frequency-range vernier and sync-signal controls are adjusted until the audio component of the modulated wave is synchronized with the sweep, as indicated by a stationary pattern. When voice modulation is used, a rapidly changing pattern of varying height is obtained.

When the maximum height of the pattern is twice that of the unmodulated carrier, the carrier is modulated 100 percent. Several operating conditions are shown in figure 8-25A. In order to determine the modulation percentage for any value below 100-percent modulation, the following procedure is followed:

The peak-to-peak height (H_2) of the unmodulated carrier is subtracted from the peak-to-peak height (H_1) of the modulated carrier, and the difference divided by the peak-to-peak height (H_2) of the unmodulated carrier. The result is then multiplied by 100 to give the percentage of modulation. As a formula,

$$\text{modulation percentage} = \frac{H_1 - H_2}{H_2} \times 100.$$

The Trapezoidal pattern is more difficult to obtain, but it gives more accurate information, particularly when nonsinusoidal waveforms are encountered. As indicated in figure 8-25B, the vertical plates of the CRT are connected via the small pickup loop to the final tank circuit. The voltage divider, R1 and R2, across the modulation transformer secondary and the high voltage power supply provides the a-f voltage component that is applied to the horizontal input in lieu of the saw-tooth sweep frequency. Potentiometer R1 is varied until a satisfactory sweep is obtained on the screen of the CRT. The percentage of modulation is calculated in the same manner as that of the wave-envelope pattern.

TYPICAL DUAL-TRACE OSCILLOSCOPES—TEKTRONIX TYPES 535A/545A

The Tektronix type 535A/545A oscilloscopes are wide-range general-purpose laboratory instruments. The type 535A (figure 8-26) provides accurate measurements in the d-c to 15 mc range while the type 545A covers the range of d-c to 30 mc. Both instruments can be operated with any Tektronix letter-series plug-in unit to satisfy the requirements for virtually any application.

All specifications for the vertical-deflection system depend on the type of vertical plug-in unit used with the instrument. Following is the description of a commonly used plug-in unit.

Type CA Plug-in Unit

The Type CA Unit (lower left beneath CRT in figure 8-26) contains two identical amplifier

channels that can be electronically switched either by the oscilloscope sweep or at a free-running rate of approximately 100 kc. When amplifier switching is triggered by the oscilloscope sweep, the two signals to be compared appear on alternate sweeps. Because the sweeps are identical, and time-delay characteristics of the two amplifier channels are closely controlled, time comparisons accurate within 1 nano second can be made.

Stationary display of two signals unrelated in frequency can be accomplished by internal triggering of the sweep alternately by the two signals. In free-running operation, switching occurs at a rate of approximately 100 kc, making it possible to view two simultaneous transients. Transients of as little as one-millisecond duration can be well delineated, with about one hundred elements in each trace. For many purposes, shorter transients can be adequately observed.

Either amplifier channel can be used separately without electronic switching, making the Type CA also useful in all single-trace applications within its frequency-response and sensitivity capabilities. Maximum flexibility is obtained by providing separate positioning, sensitivity, and polarity-inverting controls for each channel.

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Figure 8-26.–TEKTRONIX 535A, Cathode Ray Oscilloscope.

By placing the MODE switch in the ADDED ALGEBRAICALLY position the output of both channels may be combined, adding or subtracting according to the settings of the polarity switches.

TYPE CA SPECIFICATIONS.–

Operating Modes.–
Channel A only.
Channel B only.
Electronic switching at 100 kc (chopped).
Electronic switching on alternate sweeps.
Both channels combined at output (A±B).

Amplifier Sensitivity.–Basic deflection factor–.05 v/cm, a-c or d-c. Nine calibrated sensitivities–.05 v/cm to 20 v/cm, accurate within 3% when set on any one step.

Input Impedance.–1 megohm shunted by 20 $\mu\mu$f, with P410 probe 10 megohms, 7.5 $\mu\mu$f.

FUNCTIONS OF CONTROLS AND CONNECTORS.–

Channel A. Channel B.–Signal input of the A-channel or B-channel amplifier.

D-C-A-C.–Slide switch to provide either a-c or d-c coupled input into the amplifiers.

Volts/CM.–Nine-position switch used to select the calibrated vertical-deflection sensitivities.

Variable.–Potentiometer concentric with the VOLTS/CM switch to provide continuously variable attenuation between the calibrated sensitivities and to extend the attenuation to a sensitivity of 50 v/cm.

Polarity.–Two-position switch to provide optional in-phase or out-of-phase output.

OPERATION.–Either of the two identical amplified channels can be used independently by turning the MODE switch to A ONLY or B ONLY and connecting the signal to be observed to the appropriate input. The following remarks apply equally well to either amplifier channel.

Use of Probe.–The Type P410 probe, furnished with the 540-Series Oscilloscopes, is designed to preserve the transient response of

this unit. This probe introduces no ringing but causes an additional frequency-response loss of less than 1 db at 24 mc. The Type P410 probe has a 10-to-1 attenuation ratio.

The adjustment of the probe must be checked when first connected to a plug-in unit or oscilloscope. The probe compensation is a function of the shunt input capacitance of the particular plug-in unit or oscilloscope that is used with the probe. If the compensation is incorrect the frequency response will be affected. Touching the probe tip to the calibrator output connector will display several cycles of the calibrator waveform. If the top and bottom of the displayed square wave are not flat, the trimmer capacitor located either inside the probe body or inside the box at the other end of the cable should be adjusted to achieve correct square-wave response.

Input Coupling.–It is sometimes undesirable to display the d-c level of the waveform being observed. Placing the AC-DC switch in the AC position inserts a capacitor in series with the input so the d-c component of the waveform is blocked and only the a-c component is displayed. The low-frequency response is about 2 cps when a-c coupling is used.

Output Polarity.–It will be desirable to invert the displayed waveform at times, particularly when using the dual-trace feature of the Type CA. The POLARITY switch has two positions. In the NORMAL position the displayed waveform will have the same polarity as the input signal. In the INVERTED position the displayed waveform will be turned upside down; that is, a positive-going pulse will be displayed as a negative-going pulse.

D-C Balance Adjustment.–After the plug-in unit has been in use for a period of time the trace will change position as the VARIABLE control is rotated. This is caused by tube aging and the resultant shift in operating potentials. To correct this condition the VARIABLE control is rotated back and forth and the DC BAL control adjusted until the trace position is no longer affected by rotation of the VARIABLE control.

Gain Adjustment.–Aging of the tubes will also affect the gain of the plug-in unit. Display a calibrator waveform of 0.2 volt peak to peak with the VOLTS/CM switch in the .05 position. Adjust the GAIN ADJ control until the displayed waveform is 4 graticule divisions in amplitude. Make sure the VARIABLE control is turned full right to the CALIBRATED position before making this adjustment.

Positioning Adjustment.—The VERT POS RANGE control balances the d-c output level so the full range of the front-panel positioning controls can be utilized. This control is accessible when the left side panel is removed. Center the trace in both the A ONLY and B ONLY positions of the MODE switch. Note the settings of the VERTICAL POSITION controls. Adjust the VERT POS RANGE control so both the A-channel and B-channel VERTICAL POSITION controls are approximately centered when the displayed trace is centered.

Delayed Horizontal Display

Special circuits incorporated in the Type 535A and Type 545A Oscilloscopes permit an accurate, continuously variable delay in the presentation of the horizontal sweep from 1 microsecond to 10 seconds after receipt of a triggering impulse. This feature permits observation of a small portion of the normal sweep, accurate measurement of waveform jitter, precise time measurements, as well as many other uses. This is done through simultaneous use of Time Base A and Time Base B. In this application, Time Base B is used to provide the accurate time delay while Time Base A presents a normal horizontal sweep at the end of the delay period. The duration of the sweep delay is controlled by the Time Base B TIME/CM OR DELAY TIME switch and the DELAY-TIME MULTIPLIER control.

The delayed sweep feature of the Type 535A and Type 545A Oscilloscopes can be used in a number of special applications to increase the versatility of the instrument. Such applications include high magnification of a selected portion of an undelayed sweep, accurate time measurements, and accurate measurements of waveform jitter. Also, it is possible to pick off and display any desired line of a television scan or to check pulse-time modulation. In addition, the delayed sweep feature is readily adaptable to a great number of other applications.

The delayed sweep is selected when the HORIZONTAL DISPLAY switch is in the 'A' DEL'D BY 'B' position. The amount of delay occurring from the application of the triggering waveform

until the sweep runs is indicated directly by the settings of the TIME/CM OR DELAY TIME switch and the DELAY TIME MULTIPLIER control. The settings of the two controls are multiplied together to obtain the actual delay time. For example, if the TIME/CM OR DELAY TIME switch is set at 1 MILLISEC and the vernier dial of the DELAY TIME MULTIPLIER control indicates 6.75, the delay time is 6.75 milliseconds. When the Time Base A STABILITY control is in the fully clockwise position, the horizontal sweep starts immediately at the completion of the delay period at a rate determined by the settings of the Time Base A TIME/CM controls.

There are actually two modes of delayed sweep operation available in the Type 535A and Type 545A Oscilloscopes (see figure 8-27). In one mode the delayed sweep is started immediately after the completion of the delay time. This is the mode described previously and is obtained with the Time Base A STABILITY control fully clockwise. This mode permits selection of continuously variable delay times and is the mode of operation used to make accurate time and waveform jitter measurements as well as most other measurements. In each case the waveform shown represents the input to the oscilloscope. The waveform shown in the delayed-sweep presentation boxes represents the portion of the input waveform that is actually displayed on the oscilloscope screen. Note that in Case 2 an additional triggering pulse is required before the delayed sweep will occur.

The second delayed-sweep mode is different from the first in that the sweep does not start at the completion of the delay time until a triggering waveform is applied to Time Base A. The delay time in this mode is not continuously variable and is dependent not only on the settings of the delay-time controls, but on the occurrence of the Time Base A triggering waveform as well. The primary purpose of this mode is to eliminate jitter from the displayed waveform. Since the sweep is triggered by the input waveform, jitter is eliminated from the display even though it is inherent in the input waveform.

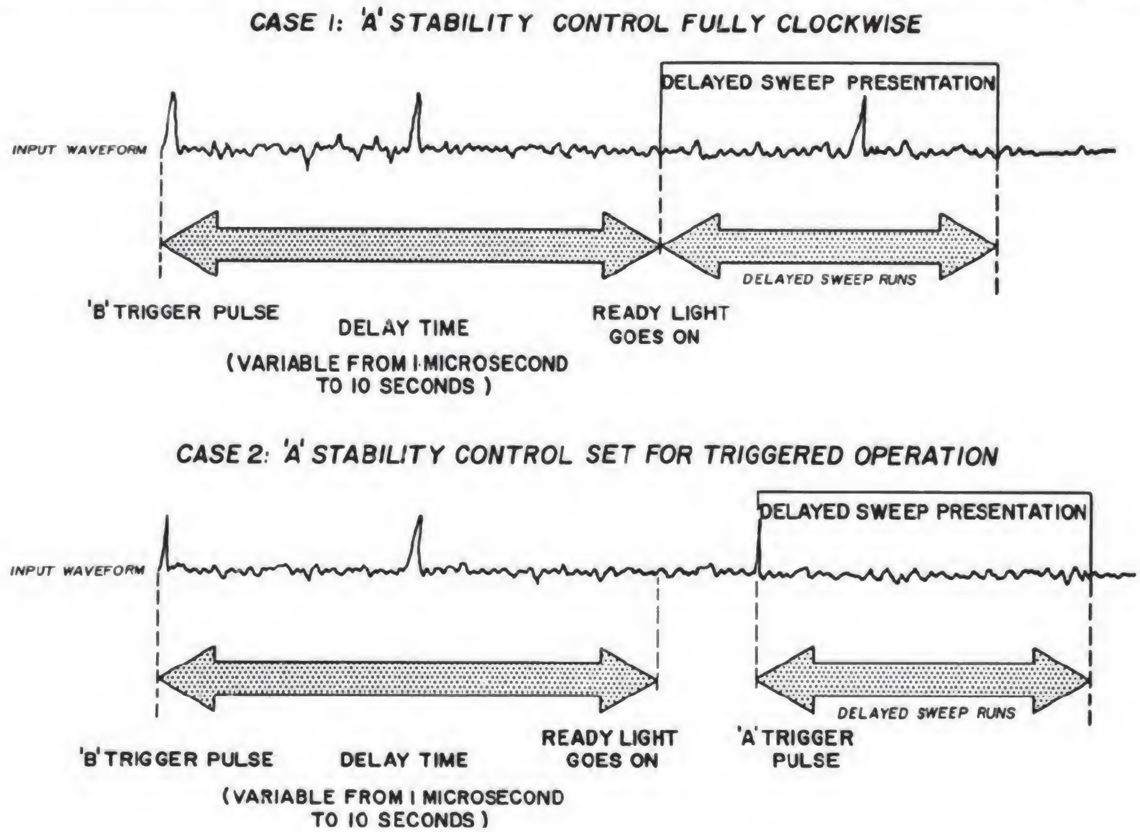

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Figure 8-27.—Comparison of the two delayed-sweep modes.

Voltage Measurements

The Type 535A or Type 545A Oscilloscope can be used to measure the voltage of the input waveform by using the calibrated vertical-deflection factors of the instrument and associated plug-in unit. The method used for all voltage measurements is basically the same although the actual techniques vary somewhat depending on the type of voltage measurements required. Essentially there are two types of voltage measurements: ac-component voltage measurements and instantaneous voltage measurements with respect to some reference potential. Many waveforms contain both a-c and d-c voltage components. It is often necessary to measure one or both of these components.

When making voltage measurements, you should display the waveform over as large a vertical portion of the screen as possible for maximum accuracy. Also, it is important that you do not include the width of the trace in your measurements. You should consistently make all measurements from one side of the trace. If the bottom side of the trace is used for one reading, it should be used for all succeeding readings. The VARIABLE VOLTS/CM control must be in the CALIBRATED position.

A-C Component Voltage Measurements

To measure the a-c component of a waveform, the plug-in unit input selector switch should usually be set to one of the AC positions. In these positions only the a-c components of the input waveform are displayed on the oscilloscope screen. However, when the a-c component of the input waveform is of very low frequency it is necessary to make voltage measurements with the input selector switch in one of the DC positions to prevent errors.

Instantaneous Voltage Measurements

The method used to measure instantaneous voltages is virtually identical to the method described previously for the measurement of the a-c components of a waveform. However for instantaneous voltage measurements the plug-in unit input selector switch must be placed in one of the DC positions. Also since instantaneous voltages are measured with respect to some potential (usually ground) a reference line must be established on the oscilloscope screen which corresponds to that potential. If, for example, voltage measurements are to be made with respect to +100 volts, the reference line would correspond to +100 volts.

Time Measurements

The calibrated sweeps of the Type 535A and Type 545A Oscilloscopes cause any horizontal distance on the screen to represent a definite known interval of time. Using this feature you can accurately measure the time lapse between two events displayed on the oscilloscope screen.

Frequency Measurements

Using one of two methods described in the previous section, you can measure the period (time required for one cycle) of a recurrent waveform. The frequency of the waveform can then easily be calculated since frequency is the reciprocal of the period. For example, if the period of a recurrent waveform is accurately measured and found to be 0.2 microseconds, the frequency is the reciprocal of 0.2 microseconds, or 5 mc .

At any given oscilloscope sweep speed, the number of cycles of the input waveform that is displayed on 10 centimeters of the screen is dependent on the frequency of the input waveform. At a sweep speed of .1 microseconds per centimeter, for example, 6 cycles are displayed with a 6 mc input signal, 5 cycles with a 5 mc signal, and 4 cycles with a 4 mc input signal. By utilizing the pattern of these observations you can measure frequencies by counting the number of cycles of a waveform on 10 centimeters of the screen and multiplying this number by a factor which is dependent on the sweep speed used. Since each sweep speed produces a definite fixed multiplication factor, frequencies can usually be measured by this method much faster than by the previous method.

THE AN/USM-105

Another typical and widely used dual-trace oscilloscope which the CT M will encounter is the AN/USM-105 (figure 8-28). With the exception of the physical locations of the controls this oscilloscope is operated similarly to the Tektronix 535A/545A.

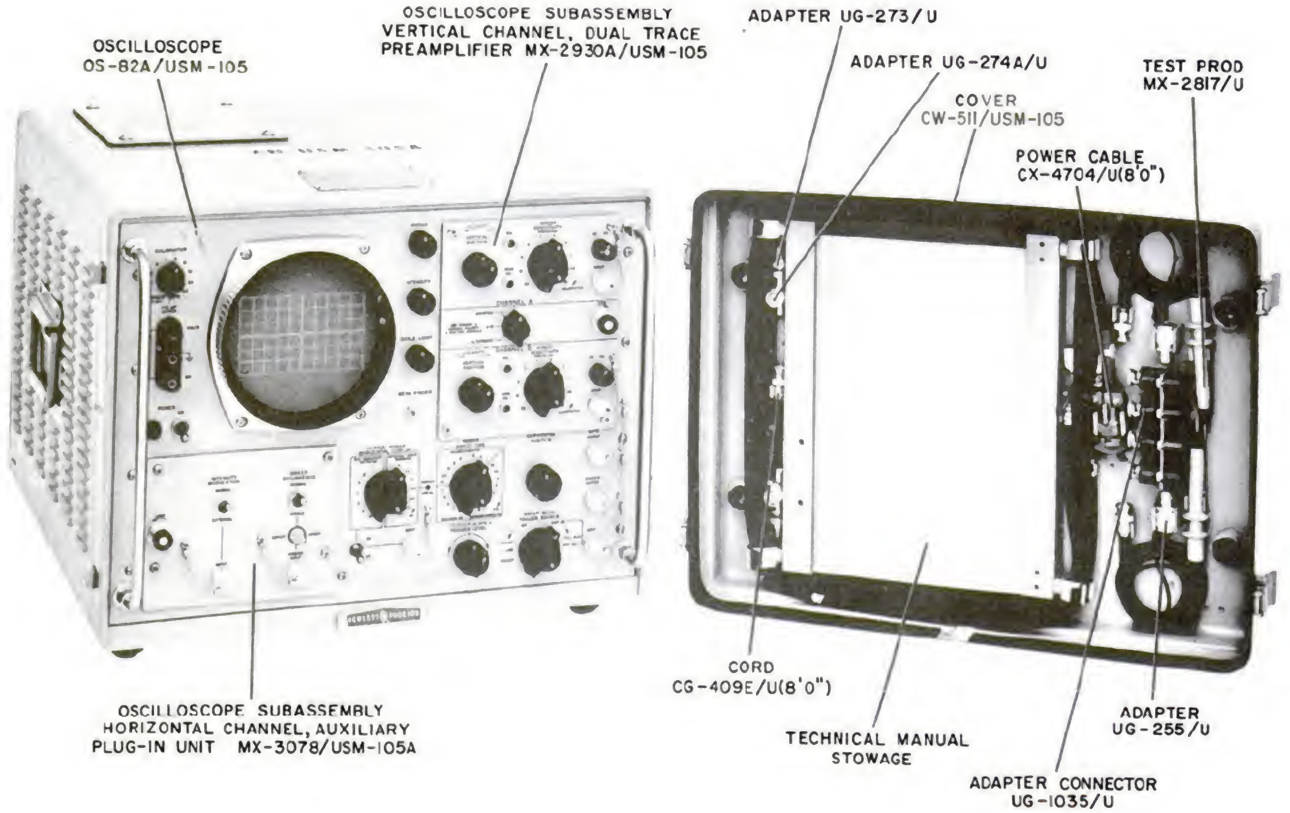

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Figure 8-28.—Oscilloscope AN/USM-105A.

RESISTANCE, CAPACITANCE, AND INDUCTANCE BRIDGE

A bridge-type instrument like the ZM-11/U may be used to make resistance, capacitance, and inductance measurements. A brief description of the basic circuitry of this instrument and the methods of making these measurements follows.

A view of the instrument is shown in figure 8-29.

RESISTANCE MEASUREMENTS

When the FUNCTION switch (upper left of figure 8-30) of the ZM-11/U is in the RESISTANCE (R) position, the circuit shown in simplified form in figure 8-30 is selected by the switch.

The four arms of the bridge are shown in the schematic diagram. Arm A contains the multiplier rheostat and a fixed resistor. When the multiplier rheostat is in position 1, arm A has a resistance of 1000 ohms; as it is moved to position 11, the resistance of arm A increases to 11,000 ohms. Arm B contains the range switch and the range resistors. Arm R_S, contains one of the standard resistors; the correct standard resistor is connected into this arm by the range switch. The resistor of unknown resistance is connected in arm R_X.

The balance indicator is an electron-tube tuning indicator. The maximum possible opening of the pattern indicates balance. Balance is approached by proper positioning of the range switch, which connects the correct resistor

in arm B and the correct standard resistor in arm R_S; balance is then completed by adjustment of the multiplier rheostat.

As the multiplier is moved through the point of balance, the balance indicator pattern increases to a maximum (point of balance) and then decreases again. This action results from the fact that the voltage across the indicator decreases to zero as the exact point of balance is reached and then it increases again as the multiplier is moved beyond the point of balance. The same reasoning may also be applied to capacitance and inductance measurements.

As a practical example of resistance measurement, assume that at balance the multiplier is at position 2 (the resistance of arm A is 2000 ohms), the range switch is in the position shown (100 ohms in arm B), and that 100 ohms standard is used in arm R_S. These positions are indicated in the figure.

Under conditions of balance,

$$\frac{A}{B} = \frac{R_X}{R_S},$$

where A is the resistance of arm A, B is the resistance of arm B, R_X is the resistance of the unknown resistance, and R_S is the resistance of the standard resistor.

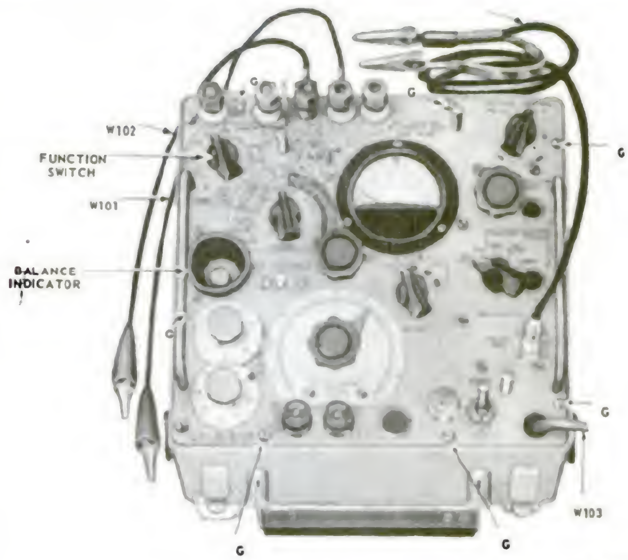
Substituting the values previously given,

$$\frac{2000}{100} = \frac{R_X}{100}$$

$$R = \frac{2000 \times 100}{100} = 2000 \text{ ohms.}$$

On the instrument itself, the range switch (which has a calibrated dial) will indicate 1000 ohms, and the multiplier dial (which is also calibrated in units and tenths—from 1 to 11) will indicate 2; the reading will therefore be 2000 ohms. That is, 1000 ohms on the range switch multiplied by 2 on the multiplier dial is equal to 2000 ohms.

The same procedure is followed in making capacitance and inductance measurements. In each case the range switch indication is multiplied by the multiplier dial indication to determine the value of the unknown capacitor or inductor.



1.68

Figure 8-29.—ZM-11/U bridge.

CAPACITANCE MEASUREMENTS

When the FUNCTION switch of the ZM-11/U is in the CAPACITANCE (C) position, the circuit shown in simplified form in figure 8-31 is selected by the switch.

The four arms of the bridge are shown in the figure. Arm A contains the stray capacitance compensator. This compensator is used only on the lower capacitance ranges, and is automatically positioned by the range switch. Its function is to compensate for stray capacitance associated with the connecting leads in arm C_X. The error that would otherwise be introduced is significant only when small capacitances are measured, and the lead capacitance is of the same order of magnitude as that of the capacitor itself. Arm A also contains the multiplier resistor and a 1000-ohm fixed resistor. When the multiplier is in position 1, the resistance of arm A is 1000 ohms. The resistance increases to 11,000 ohms when the multiplier is moved to position 11.

Arm B contains the range switch and the range resistors, and arm C_X contains the capacitor of unknown capacitance.

Arm C_S contains a standard capacitor (one of two), which is selected automatically by the range switch, and the necessary dissipation control rheostat. The dissipation (D) dial associated with the rheostat indicates the

dissipation factor (power factor) of the capacitor under test. Each of the two standard capacitors has its associated dissipation control rheostat. When the 1000 $\mu\mu$f standard is used, the 10,000-ohm rheostat is in the circuit. As the resistance of the rheostat is increased through the 10,000-ohm range, the D dial indicates a dissipation factor of from 0 to 0.06. When the 1.0 μf standard is used, the 100-ohm rheostat is in the circuit. As the resistance of the rheostat is increased through the 100-ohm range, the D dial again indicates a dissipation reading of from 0 to 0.6, but in this case, the reading must be multiplied by 10 to obtain the dissipation factor (0 to 0.6).

As a practical example, assume that at balance the controls are in the positions shown. Arm A has a resistance of 2000 ohms, arm B has a resistance of 100 ohms, arm C_s utilizes the 1000-$\mu\mu$f standard with a certain amount of resistance in series with it, and arm C_x contains the capacitor of unknown capacitance with its effective series resistance. Because the purpose of the dissipation rheostat is to make the power factor of arm C_s equal to the power factor of arm C_x to perfect the bridge balance, the resistance of the rheostat need not be considered in the following bridge equation:

Under conditions of balance,

$$\frac{A}{B} = \frac{C_x}{C_s}$$

Performing the substitutions,

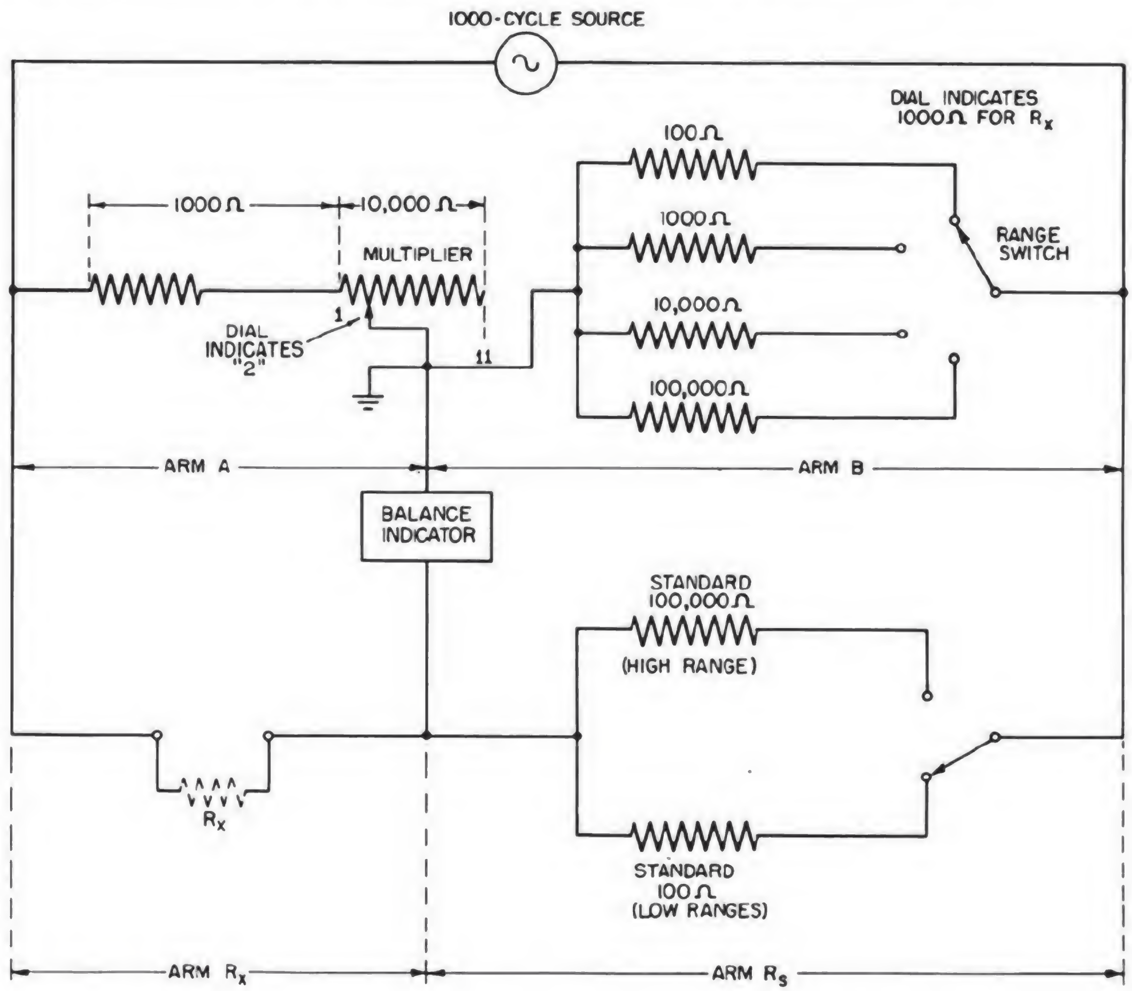


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Figure 8-30.—Resistance bridge.

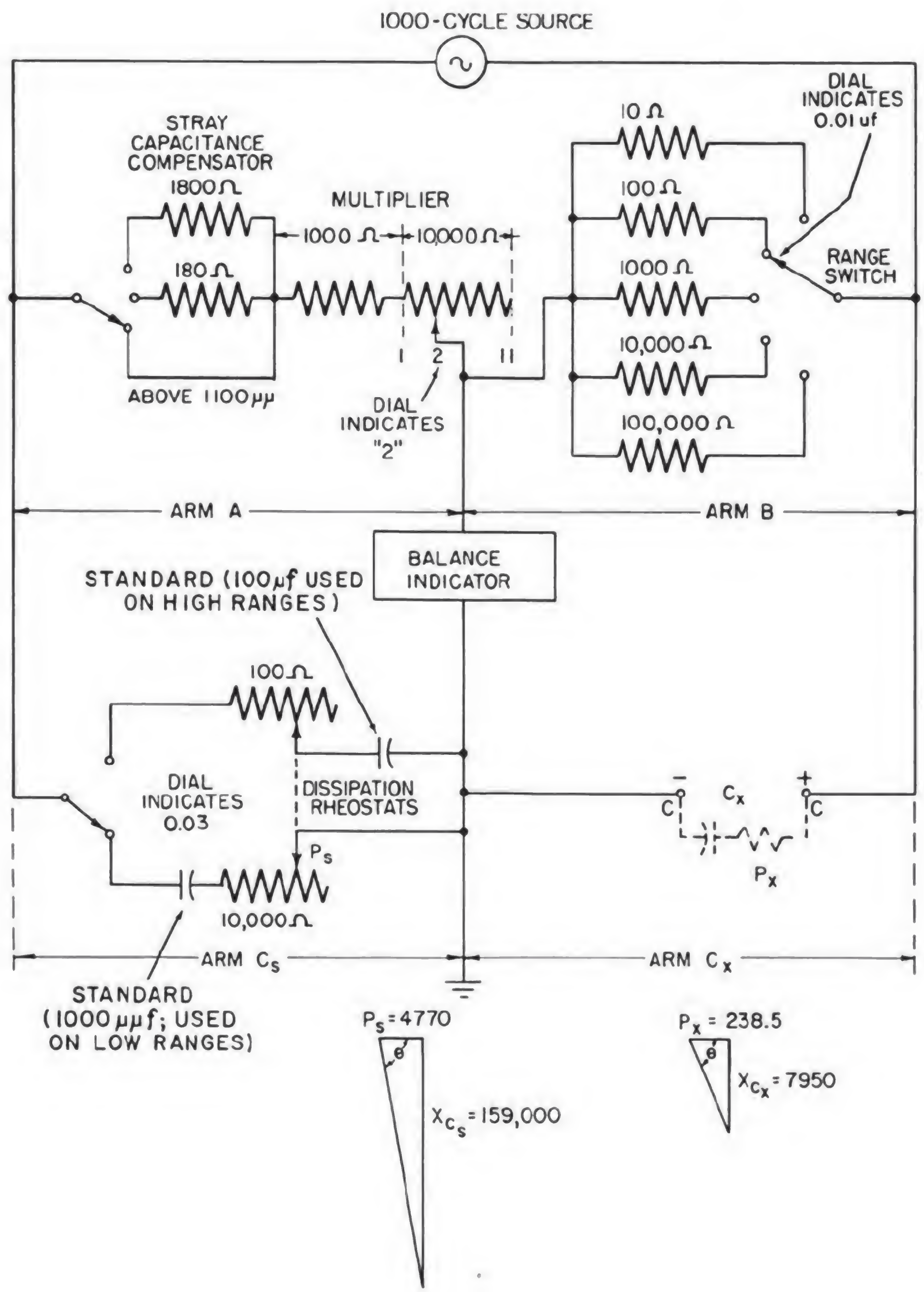

Figure 8-31.—Capacitance bridge.

$$\frac{2000}{100} = \frac{C_X}{1000}$$

$$C_x = \frac{2000 \times 1000}{100} = 20{,}000\,\mu\mu f = 0,02\mu f.$$

Under conditions of balance, the power factor ($\cos\theta$ D) of arm C_S is equal to the power factor of arm C_X. The calculations for the reactance and resistance of arms C_S and C_X for this example are

$$X_{CX} = \frac{1}{2\pi f C_X} = \frac{10^{12}}{6.28 \times 10^3 \times 2 \times 10^4} =$$

7950 ohms

$$X_{CS} = \frac{1}{2\pi f C_S} = \frac{10^{12}}{6.28 \times 10^3 \times 10^3} =$$

159,000 ohms

$$P_X = X_{C_X} \cos\theta = 7950 \times 0.03 =$$

238.5 ohms

$$P_S = X_{C_S} \cos\theta = 159{,}000 \times 0.03 =$$

4770 ohms.

On the instrument itself, the range switch will indicate 0.01μf, and the multiplier dial will indicate 2; the reading will therefore be 0.02 μf. That is, 0.01μf on the range switch multiplied by 2 on the multiplier dial is equal to 0.02 μf. The calibrated dissipation dial will indicate some value—for example, 0.03 (or a 3% power factor). The larger the dissipation of the capacitor under test the larger will be the value of the dissipation rheostat resistance in series with the standard.

The relation between resistance, reactance, and impedance in the capacitor arms of the bridge for the preceding example is represented by the two impedance triangles in the lower position of figure 8-31. The triangles are similar but not equal.

They are not drawn to scale; the length of the base lines is exaggerated in order to show clearly the effective series resistances, P_S and P_X, in their respective arms.

Because the power factor is low (0.03), θ is almost 90°, and the impedance (hypotenuse) is assumed to be equal to the reactance (altitude) of the right triangle. The base of the triangle represents the effective series resistance in each case.

INDUCTANCE MEASUREMENTS

When the FUNCTION switch of the ZM-11/U is in an INDUCTANCE position (either L (Q) or L (D) position), the circuit shown in simplified form in figure 8-32, is selected by the switch.

Because this circuit is somewhat more complex than those discussed previously, the circuit is further simplified into parts B and C.

The circuit shown in part B is selected when the FUNCTION switch is in the L (D) position. This circuit is used when the dissipation, D, is less than 0.05. Arm A contains the multiplier and a fixed resistor connected in series. Arm C_S contains one of the standard capacitors and its associated dissipation rheostat connected in series (capacitance standards are used in the inductance bridge to reduce the total number of standards needed). Arm B contains one of the range resistors, and arm L_X contains the inductor of unknown inductance. Arm L_X also contains P_X, the effective series resistance of arm L_X (P_X is, of course, a part of the impedance of arm L_X).

The circuit shown in part C is selected when the FUNCTION switch is in the L (Q) position. This circuit is used when the dissipation, D, is greater than 0.05. This circuit is essentially the same as the one shown in part B, except for arm C_S. In arm C_S the shunt rheostat, S, shunts the standard capacitor, C_S. This rheostat is positioned by means of the Q dial. Q is the merit factor of a coil; it is the ratio of the inductance reactance (X_L) to the resistance (R). It is also the reciprocal of the dissipation factor—that is,

$$Q = \frac{1}{D}$$

As a practical example, assume that the inductance of a high-Q coil is being determined by means of the bridge circuit shown in part B. Assume that the inductor of unknown inductance is connected in arm L_X, that the resistance of arm A is 2000 ohms (multiplier

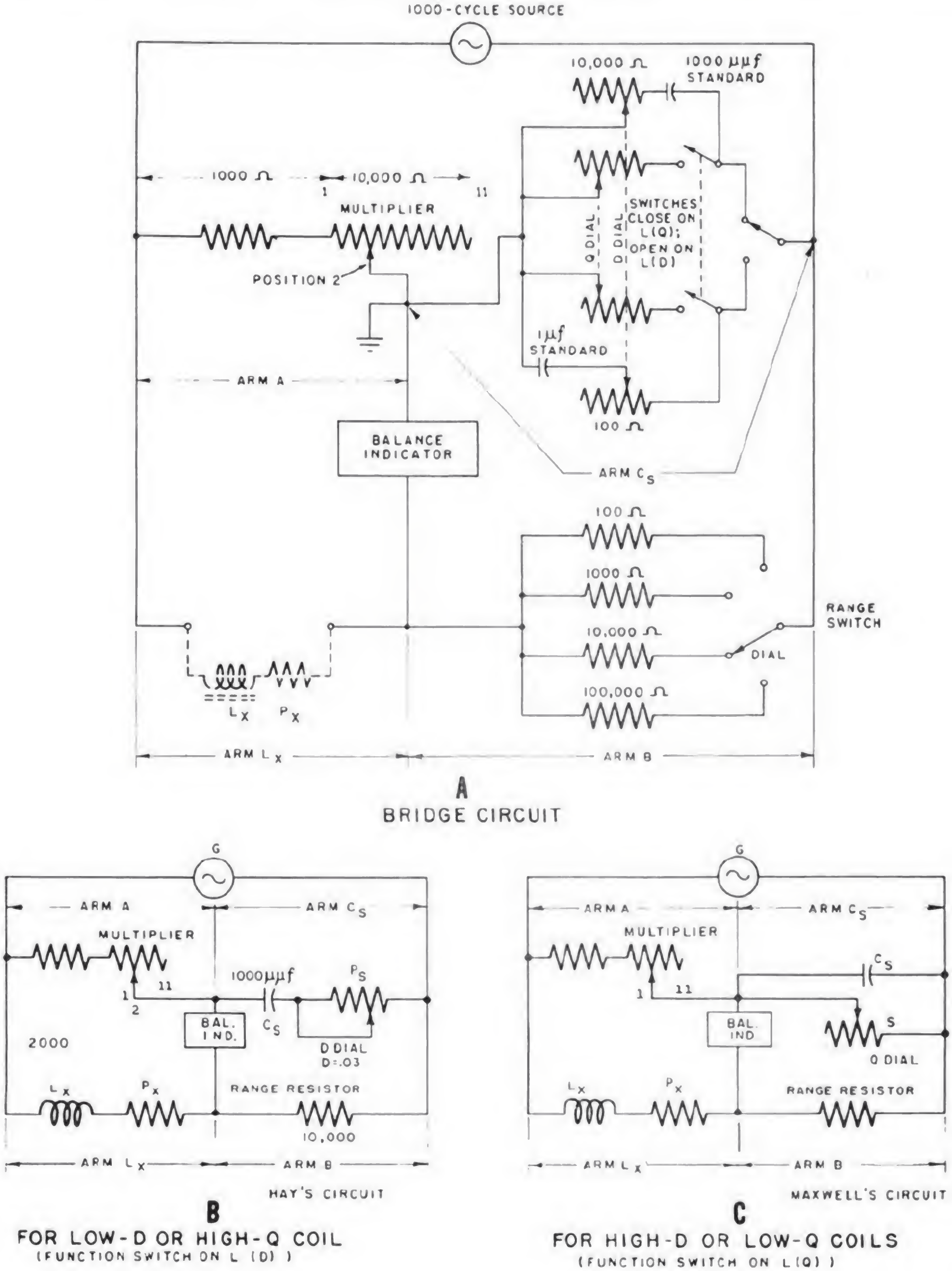

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Figure 8-32.—Inductance bridge.

dial in position 2) and that the 10,000-ohm range resistor is in arm B. Assume also that the dissipation rheostat connected to the D dial is adjusted to balance the bridge, and that the dial indicates 0.03, which is also the power factor of the inductor under test. The capacitance of the C_S arm is $1000 \mu\mu f$. At balance,

$$\frac{Z_{armL_X}}{A} = \frac{B}{Z_{armC_S}}$$

The impedance triangles shown in figure 8-33 will be helpful in illustrating how the reactance of L_X may be determined. [illegible] a power factor of 0.03, the phase angle is above 88° and so close to 90° that, for practical purposes, X_{L_X} is equal to $Z_{arm}X$, and X_{C_S} is equal to $Z_{arm}C_S$ in the figure. Therefore, the preceding equation may be written as

$$\frac{X_{L_X}}{A} = \frac{B}{X_{C_S}}$$

$$\frac{wL_X}{A} = \frac{B}{\frac{1}{wC_S}}$$

$$L_X = C_S BA.$$

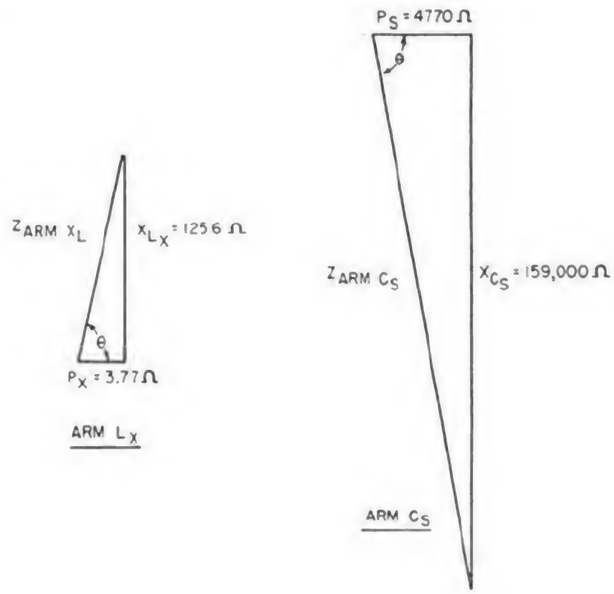
Substituting the known values,

$$L_X = 1000 \times 10^{-12} \times 10{,}000 \times 2000 = 2 \times 10^{-2} = 0.02 \text{ h.}$$

Converting to millihenries,

$$L_X = 0.02 \times 10^3 = 20 \text{ mh.}$$

On the meter itself the range switch will be on the 10-mh position, and the multiplier dial will indicate 2. The inductance of the unknown inductor will then be 10 mh x 2, or 20 mh. The dissipation will be 0.03, as previously stated.



1.72

Figure 8-33.—Impedance triangles.

The relationship between resistance, reactance, and impedance in the capacitance and inductance arms of the bridge for the preceding example is represented by the two impedance triangles of figure 8-33. The calculations are

$$X_{L_X} = 2\pi fL = 6.28 \times 10^3 \times 2 \times 10^{-2} = 125.6 \text{ ohms.}$$

$$X_{C_S} = \frac{1}{2\pi fC} = \frac{10^{12}}{6.28 \times 10^3 \times 10^3} = 159{,}000 \text{ ohms.}$$

$$P_X = X_L \cos\theta = 125.6 \times 0.03 = 3.77 \text{ ohms.}$$

$$P_S = X_{C_S} \cos\theta = 159{,}000 \times 0.03 = 4770 \text{ ohms.}$$

AUDIO FREQUENCY SIGNAL GENERATOR

The Model 200AB Audio Frequency Signal Generator, shown in figure 8-34 is a

representative equipment which the CT M will use in ringing out audio telephone lines, checking out multi-channel tone terminal equipment, and similar applications. This signal generator is designed for general purpose audio testing and measurements. The resistance-capacity oscillator used in this instrument will retain its high degree of accuracy for long periods of time with no adjustments. The push-pull output amplifier used in the Model 200AB has a large amount of overall negative feedback for maximum stability and low distortion. The output impedance of the instrument is 600 ohms balanced or unbalanced. The output voltage is adjustable from 0 to 24.5 volts (1 watt) across a 600 ohm resistive load over the full range of 20 to 40,000 cps and is sufficient for modulating radio-frequency signal generators or other applications that require considerable power.

1.318X
Figure 8-34.—Audio Frequency Generator, HP-200 series.

RADIO FREQUENCY SIGNAL GENERATOR

The RF Signal Generator Set AN/URM-25 is a test instrument for generating radio frequency signals, either modulated or unmodulated, over a continuous range of frequencies from 10 to 50,000 kilocycles. One of its principal attributes is that it has been miniaturized physically without any loss of accuracy or applicability.

All units including the power supply, are incorporated in a single portable cabinet (See figure 8-35.)

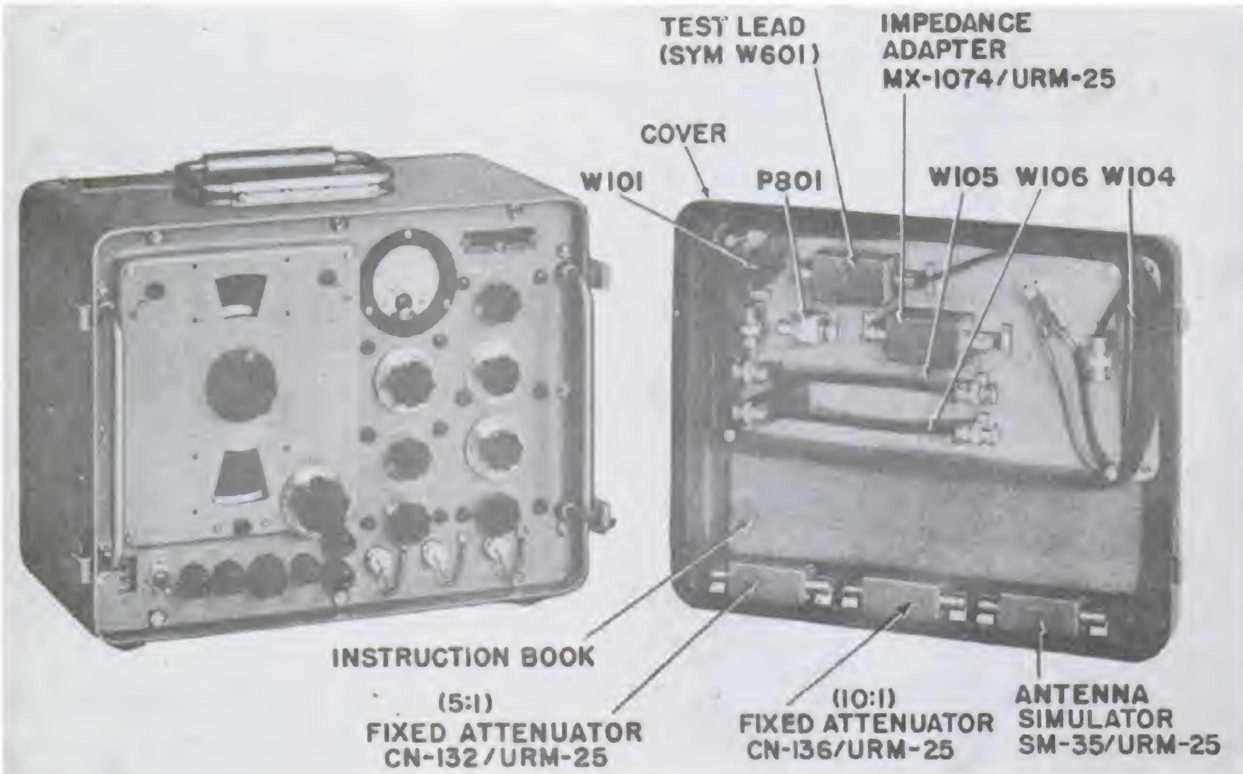
The AN/URM-25 operates from a source potential of approximately 103 to 126 volts, 50 to 1600 cycles, single phase alternating current. The equipment is so constructed and shielded that an accurate, known radio frequency voltage is available at its output terminals in varying strength as indicated by a meter and associated multiplier indicator.

The rated frequency range is 10 kilocycles to 50,000 kilocycles per second. This range is covered in eight bands by a band selector switch located on the front panel. Within each band the frequency is varied by means of a straight line frequency capacitor. Percentage frequency change is therefore proportional to capacitor dial rotation. The frequency generated can be read from a main frequency scale, which is geared to this variable capacitor.

The output is continuously variable from 0.1 to 100,000 microvolts and is determined by a meter reading in association with a multiplier and external attenuator settings. An adjustable two volt, open circuit output is also available.

The output may be either modulated or unmodulated. Modulation is adjustable between 0 and 80 percent. An internal modulation source of either 400 or 1000 cycles per second is provided. Provision is also made for external modulation.

The functional principle of the AN/URM-25 (figure 8-36) is similar to that of a radio frequency transmitter. A carrier oscillator generates a variable r-f signal which is applied to the control grid of a buffer-amplifier. A modulation oscillator generates an audio voltage (400 to 1000 cycles) which is also applied to the control grid of the buffer-amplifier to grid modulate the r-f signal. The modulated signal is then taken from the buffer-amplifier and



20.335

Figure 8-35.—RF Signal Generator Set AN/URM-25, Complete Equipment.

fed to a step attenuator circuit where the desired output amplitude is selected. An electron tube voltmeter, consisting of an r-f diode, modulation diode and voltmeter bridge, is provided for measuring the carrier output and percentage modulation. Provision is also made for external modulation.

FREQUENCY METER

The FR-36/U (figure 8-37) equipment is intended for measuring the frequencies of radio transmitters, or for setting radio receivers to designated frequencies, in the range of 160 kc to 30 mc. By harmonic extension, frequencies above 30 mc may be measured. The equipment is accurate to ± 0.003 percent or ± 50 cycles, whichever is greater.

The equipment consists of a single unit containing the Power Supply, Heterodyne Frequency Meter, Crystal Calibrator, Detector-AF Amplifier and Interpolator (electronic frequency meter).

When measuring an unknown frequency, the Heterodyne Frequency Meter combines with the unknown frequency to produce beats in the detector which are amplified in the audio frequency amplifier and heard in the headphones. The Heterodyne Frequency Meter output is made equal in frequency to the unknown frequency by adjusting the Heterodyne Frequency Meter for a zero beat in the headphones. A beat is then obtained between a harmonic of the Calibrator and the fundamental frequency of the Heterodyne Frequency Meter. The Interpolator indicates on a front panel meter the value of this beat frequency. The value of the frequency being measured is then given by the sum of the Calibrator harmonic frequency

and the beat frequency indicated by the Interpolator.

To set up a designated frequency, the Heterodyne Frequency Meter is combined with the harmonic output of the Calibrator to produce a beat frequency as indicated on the Interpolator. The value of the frequency being set up is then given by the sum of the Calibrator harmonic frequency and the beat frequency indicated by the Interpolator.

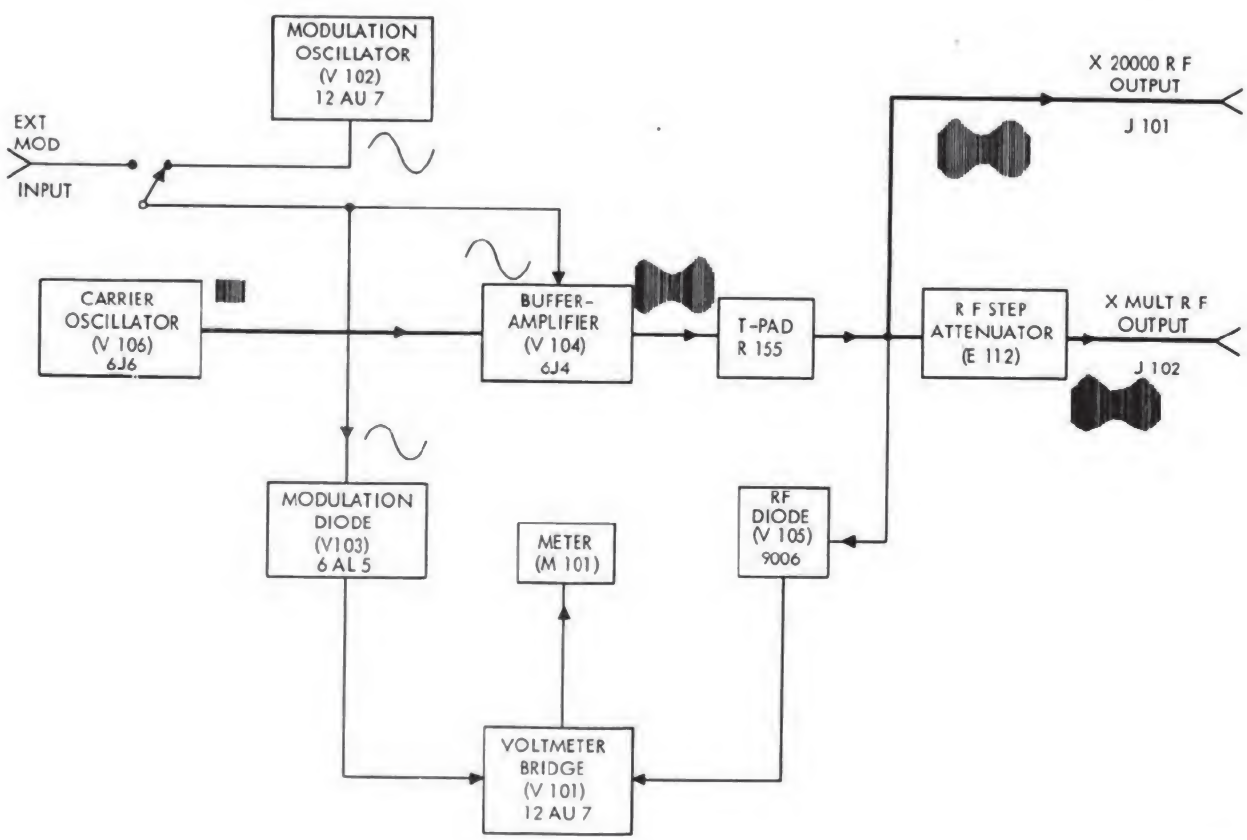
The equipment is assembled in a single unit which is housed in a metal cabinet. The equipment is removed from the cabinet by releasing the four fasteners in the corners of the panel and drawing the instrument forward on the slide carrier. The equipment has been designed so that each major electrical section is located on a separate physical assembly.

The front panel contains all the necessary controls for the designed operation of the equipment.

The Heterodyne Frequency Meter contains 13 effective tuning bands:

BAND	RANGE OF EACH BAND
1	160 kc to 232 kc
2	232 kc to 330 kc
3	330 kc to 470 kc
4	470 kc to 660 kc
5	660 kc to 940 kc
6	940 kc to 1. 33 Mc
7	1. 33 Mc to 1. 87 Mc
8	1. 87 Mc to 2. 65 Mc
9	2. 65 Mc to 3. 75 Mc
10	3. 75 Mc to 5. 30 Mc
11	5. 30 Mc to 7. 50 Mc
12	7. 50 Mc to 10. 60 Mc
13	10. 60 Mc to 15. 00 Mc

Without details as to the individual components, the principles of operation of the equipment may be understood with reference to



20.335

Figure 8-36.—RF Signal Generator SG-44/URM-25, Functional block diagram.

1.319
Figure 8-37.—Frequency Meter, Navy Model FR-36/U.

figure 8-38. The general theory of operation may be outlined as follows:

In measuring a frequency (fx, introduced at the R.F. INPUT terminal) the DETECTOR INPUT switch (S103) is thrown to the MATCH position. Beats between the fundamental, or a harmonic frequency of the Heterodyne Frequency Meter (H.F.M.) and the frequency, fx, under measurement, are then produced in the detector, amplified in the audio frequency amplifier and may be heard in the headphones at J101 and J102. The Heterodyne Frequency Meter is then carefully adjusted to obtain zero beat, matching the used output frequency to the frequency being measured. This process is advantageous, particularly if the frequency, fx, being measured is intermittently applied, as by the keying of a transmitter.

Having matched the Heterodyne Frequency Meter to the frequency, fx, to be measured, the controls of the frequency meter are left strictly alone. The DETECTOR INPUT switch is then thrown to the MEASURE position, and the Calibrator is turned on by S101 (CALIBRATOR), operating at 10 kilocycles. A beat is then obtained in the detector between the fundamental frequency of the Heterodyne Frequency Meter and a harmonic of the Calibrator. This beat frequency is amplified in the audio-frequency amplifier and may be heard in the headphones. This beat frequency is always less than about

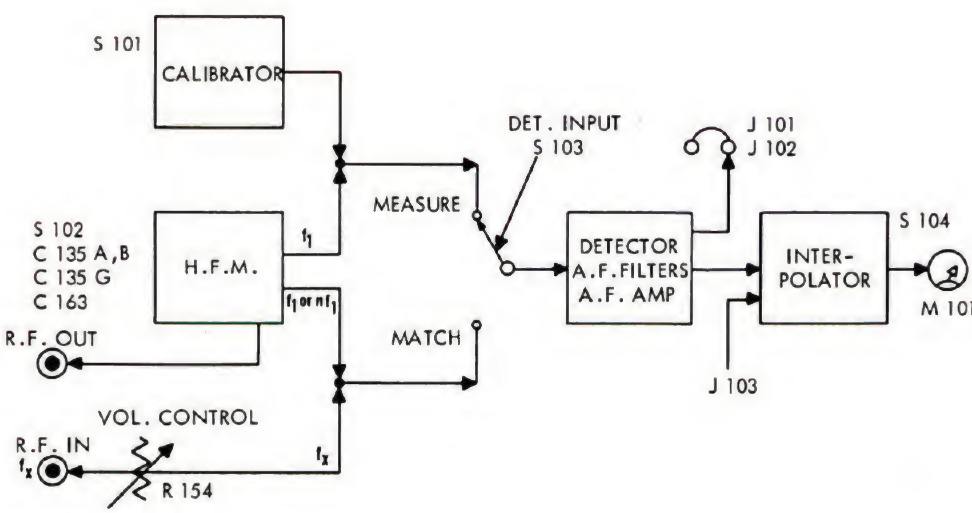


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Figure 8-38.—Block diagram of FR-36/U Equipment.

five kilocycles. While an output voltage is applied to the headphones so the beat frequency may be heard, a voltage is also applied to the Interpolator which automatically indicates on the INTERPOLATOR meter the value of this beat frequency. The value of the frequency being measured is then given by the sum of the Calibrator harmonic frequency and the beat frequency indicated by the Interpolator. The Calibrator harmonic frequency is given by the H.F.M. FREQUENCY dial, and the beat frequency is given by the reading of the INTERPOLATOR meter (M101), on the proper scale.

In setting up a desired frequency, the DETECTOR INPUT switch is thrown to the MEASURE position. With the Calibrator running at 10 kc, as selected by S101, the Heterodyne Frequency Meter is set to a selected Calibrator harmonic (identified on the H.F.M. FREQUENCY dial) and then adjusted until the beat frequency, indicated on the proper scale of the INTERPOLATOR meter is of the proper value. The frequency thus set up is available at the R.F. OUTPUT terminal for use in external receivers. This frequency may be compared with an incoming signal applied at the R. F. INPUT terminal when the DETECTOR INPUT switch is thrown to the MATCH position. The beat frequency difference between the frequency set up on the Heterodyne Frequency Meter and the incoming frequency may then be heard in the headphones.

FREQUENCY COUNTER

A COUNTER type frequency meter (figure 8-39), Electronic Counter 524C/D (Hewlett-Packard), can measure frequencies from 10 cps to 10.1 megacycles and display the readings in digital form on an eight-place indicating system. In addition to making direct frequency measurements, the counter can measure periods (0 cps to 100 kc), frequency ratios and total events. A self-check feature enables an operator to verify instrument operation for most types of measurements. The internal oscillator is stable within 5 parts of 10^8 per week. Thus these counters make good secondary frequency standards.

To increase the range of measurement, seven accessory plug-in units (not shown) are available. Frequency Converter Units, Models 525A, B, and C, increase the frequency range from 10.1 to 100 mc, 100 to 220 mc, and 100 to 510 mc respectively. Video Amplifier unit 526A increases the basic set sensitivity to 10 mv in the range of from 10 cps to 10.1 mc; Time Interval unit 526B permits measuring time intervals from 1μsec to 10^7 seconds; Period Multiplier unit 526C extends the period measurement range up to 10,000 periods of unknown frequency; and Phase unit 526D permits measuring phase angle with an accuracy approaching $\pm 0.1^\circ$. In addition to the plug-ins, the Model 540B Transfer Oscillator extends, as a companion instrument, the frequency range up to 12.4 megacycles (10^9).

Measuring Frequency—The basic circuit arrangement of the Electronic counter is shown in figure 8-40. For frequency measurement the signal is fed through a Signal Gate to a series of digital type counters. A precision time interval obtained from the Time Base Section opens and closes the Signal Gate for an extremely accurate period of time, for example, 1 second. The counters count the number cycles entering through the gate during the 1-second interval and then display the total. The answer is read directly as the number of kilocycles occurring during the 1-second interval. The period of time the Signal Gate remains open is set by the FREQUENCY UNIT switch (not shown). For each position of the FREQUENCY UNIT switch the illuminated decimal point is automatically positioned so that the answer is always read directly in kilocycles. The answer is automatically displayed for a period of time determined by gate time or the setting of the DISPLAY TIME control on the front panel, whichever is greater.

Measured Period—To measure a period or time interval the application of the two signals reverses as shown by the dotted lines in figure 8-40. The period or time interval to be measured is connected to open and close the Signal Gate while one of the standard frequencies from the Time Base Section is passed through the Signal Gate to the counters. When measuring period, one cycle of the incoming signal opens the gate, the next cycle closes it. The number of cycles of the standard frequency from the Time Base that occurred during the period are then indicated on the counters. The standard frequencies obtained from the Time Base have been selected so that the answer to the measured period will always be displayed in direct-reading units of time: seconds, milliseconds, or microseconds.

Provision is also made in the circuit to permit measurement of the average of 10 periods of the unknown frequency. Higher accuracy can thus be obtained than with single period measurements.

1.321X

Figure 8-39.—Frequency Counter, HP-542C/D.

The accuracy of frequency measurements is determined by an internal oscillator and by a possible error of ±1 count that is inherent in the gate and counter type of instrument. At low frequencies, greater accuracy can be obtained by measuring the period of the signal than by measuring the frequency directly.

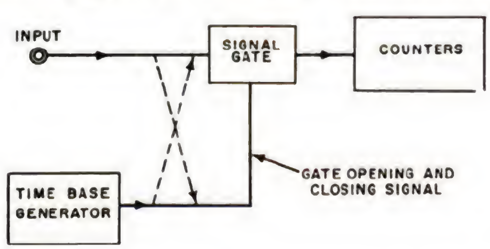

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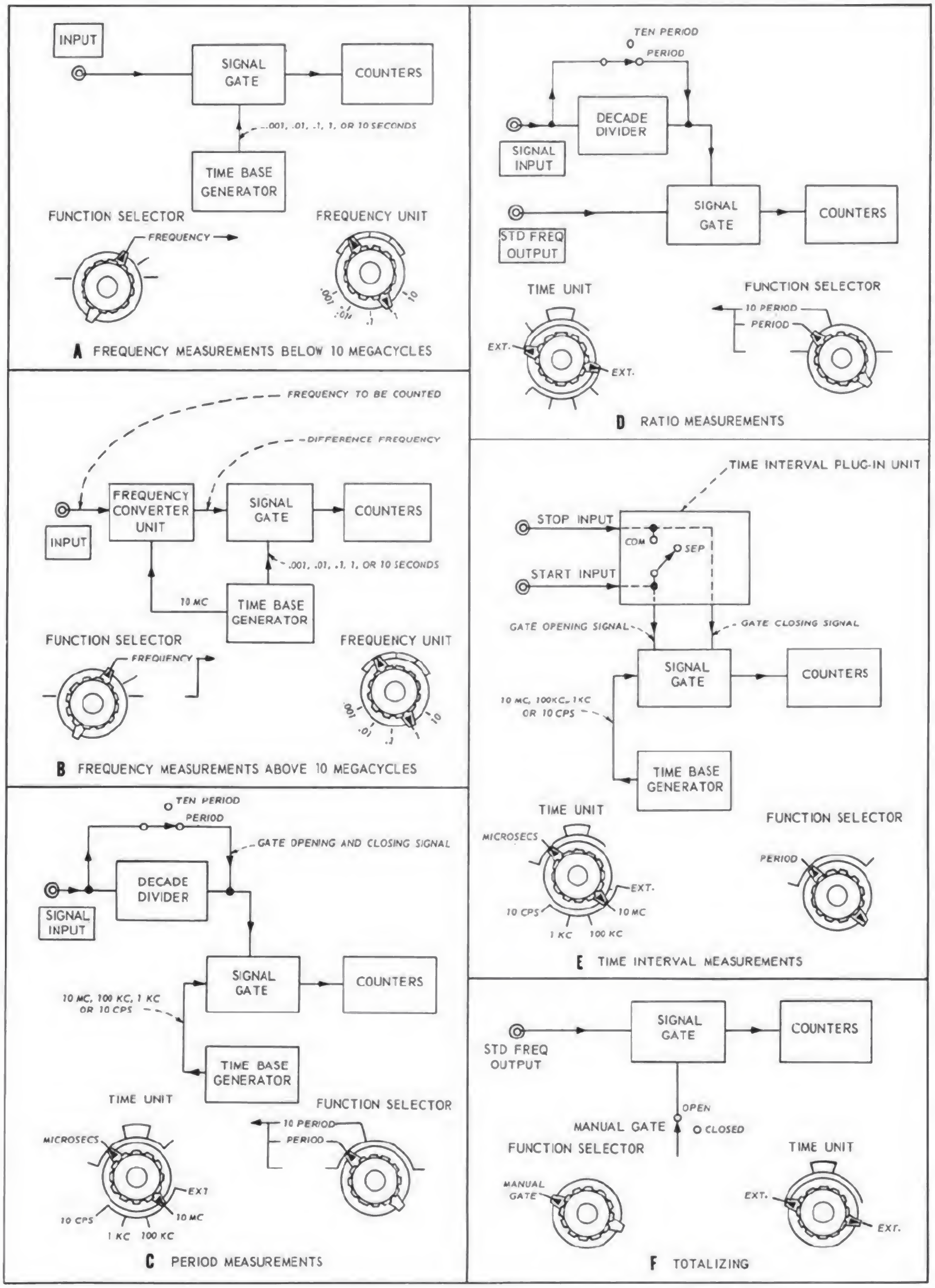
Figure 8-40.—Basic diagram of the 524D.

The block diagram (fig. 8-41A) shows the circuit arrangement of the basic counter when measuring frequencies in the range of 10 cps to 10.1 mc. To measure frequencies up to 510 mc, one of three frequency converter units is required (fig. 8-41B). As stated above, the 525C Frequency Converter unit is used between 100 and 510 mc. In these frequency converters the input signal is mixed with a harmonic of 10 mc so that the difference between the signal and the harmonic is not more than 10.1 mc. The difference frequency is counted and displayed by adding the count displayed by the counter to the known 10 mc harmonic.



70.37
Figure 8-41.—Test measurements, block diagram.

All three frequency converters have tuning systems to indicate the correct mixing frequency. However, if the mixing frequency is within 1 mc of the unknown frequency, there is a possibility of two answers, for you may not know whether to add or subtract the displayed reading from the mixing frequency. In such cases, make additional measurements using the two adjacent mixing frequencies to determine the unknown frequency. When making the final measurement choose a mixing frequency which is at least 100 kc away from the unknown.

When measuring frequency, the counter will count sine waves, rectangular waves, and positive pulses. To measure the frequency of negative pulses, adjustment of a FREQUENCY sensitivity control is necessary. This control is a screwdriver adjustment located on the front panel.

When the counter is set for PERIOD measurements, the time base and the signal input circuits are interchanged from their frequency measurement positions (fig. 8-41C). With the circuits so connected, the counters count the output of the time base for the period of the unknown input signal. Thus the standard frequencies generated in the time base are used as units of time to measure the unknown period in terms of microseconds, milliseconds, or seconds.

The accuracy of period measurements is largely determined by the accuracy with which triggering occurs at the same point on consecutive cycles of signal voltages having a slow rate-of-rise. Note that when the signal-to-noise ratio improves, the triggering accuracy also improves. Averaged over ten periods, the single-period error is reduced by a factor of ten. If you use the 526C Period Multiplier unit, the error is reduced an additional factor of ten for each factor of ten you extend the measurement. The accuracy of triggering is considerably improved when the waveforms being measured have a fast rise time. For example, you can obtain a significant reduction in error if you apply square waves instead of sine waves to the input.

In order to follow the slowest-changing waveforms, the period measurement input circuits are direct-coupled and are adjusted to trigger at the zero-volt crossing of a negative-going voltage. Thus any d-c component in the input signal will shift the triggering level so that the maximum slope no longer occurs at the zero-volt level, resulting in a loss of accuracy. If the d-c component is large enough, there may be no triggering at all. An external generator can be used in place of the time base generator for period measurements.

The counter can be used to measure the RATIO of two frequencies. The higher frequency is passed through the signal gate to the counters and is counted for a period of time determined by either one period or ten periods of the lower frequency, which controls the opening and closing of the gate (fig. 8-41D).

Ratio measurement accuracy is determined by the same factors as period measurement accuracy: consistency of triggering by the lower input frequency and the inherent error of ± 1 count of the higher frequency. The 526C Period Multiplier unit is used to reduce the error by extending the number of periods of the lower frequency over which the measurement is made. For each factor of ten the measurement is extended, the error is decreased by a factor of ten.

Although the time base generator is not used during ratio measurements, you cannot make ratio measurements if the time base generator is not operating. The counter has a holdoff circuit which disables the signal gate if the time base generator fails.

To make TIME INTERVAL measurements (figure 8-41E), the 526B Time Interval unit must be installed. Time interval measurements are similar to period measurements except that the points on the signal waveforms at which the measurement starts and stops are adjustable. The adjustable threshold feature allows you to make measurements from one part of the same waveform or to use separate waveforms as start and stop signals.

As in the case of period measurements, the input signals control the opening and closing of the gate while the standard frequencies are passed to the counters (figure 8-41E). Thus the accurate frequencies generated in the time base are used as units of time to measure the unknown interval in terms of microseconds, milliseconds, or seconds.

The threshold-selecting controls adjust the start and stop channels so that they will be actuated only by signals of predetermined polarity, amplitude, and slope. Time interval measurements begin when the start signal crosses the selected start threshold value in the selected direction and end when the stop signal crosses the selected stop threshold

value in the selected direction. The threshold controls are only approximately calibrated, and in some applications you will have to take special precautions in order to obtain the desired interval.

If you use an uncomplicated waveform as the start and/or stop signal, the setting of the threshold controls is not critical. For example, if you use a sharp pulse like that shown in figure 8-42A, there will be little difference whether the measurement begins at point A or B. However, if you use a more complex waveform like that shown in figure 8-42B to measure the interval X, set the threshold controls near zero as a preliminary adjustment. As you adjust first the start and then the stop threshold controls, you will notice definite changes in the measured time interval. Thus you know that the start and stop thresholds are above the step and that the indicated time interval is actually X.

It is highly desirable to examine both start and stop signals on a d-c coupled oscilloscope before you attempt a measurement. In this way you can determine that no spurious signals exist, and you will know how carefully you must set the threshold controls.

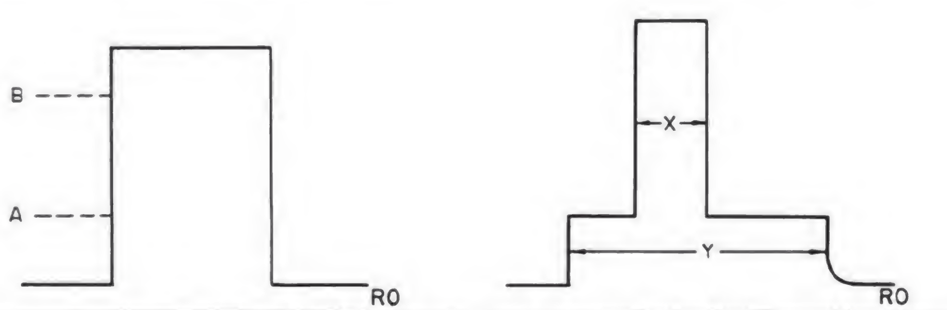
The 526B Time Interval unit may also be used as a high-speed totalizer capable of counting at a maximum rate of 10.1 million events per second. The basic circuit arrangement is indicated in figure 8-41F.

With a 526D Phase unit plugged into the counter, the phase angle between two signals of identical frequency, in the range from 1 cps to 20 kc, may be measured. This unit is useful for investigating, at various points in a circuit, the phase a signal has with respect to the phase it had at the input. Connect the reference signal to the REFERENCE INPUT, and the signal whose phase is under investigation to the UNKNOWN INPUT. If the frequency of the signal is 400 cps $\pm$ 4 cps, phase angle is read directly in tenths of a degree. For a signal of some other frequency in the rated range, the information is read in time units, with resolution up to 0.1 μ sec. For all phase measurements, set the phase unit PHASE/PERIOD switch to PHASE, the REFERENCE LEAD/LAG switch to the type of measurement desired, and the counter FUNCTION SELECTOR to PERIOD.

In general, circuit action for a phase measurement is similar to that for a time interval measurement. Trigger circuits in the Phase unit supply the pulses which open and close the signal gate in the counter. Arrangement of the circuits will be similar to that shown in figure 8-41E, for time interval measurements.

A recommended method of TUNING RADIO RECEIVERS USING A FREQUENCY COUNTER has been included in the EIB, No. 569. This method will soon become the accepted procedure for all such tuning.

The latest recommended frequency standard AN/URQ-9 (not shown) consists of three fixed frequencies. This frequency standard is a highly stable, multiple-purpose frequency standard designed for continuous-duty use aboard ship and at shore facilities. It provides three output frequencies, 5.0 mc, 1.0 mc, and 100 kc, and a regulated power output of 26.5 volts



A SIMPLE WAVEFORM SHOWING TWO POSSIBLE VOLTAGE LEVELS AT WHICH A TIME INTERVAL MEASUREMENT MAY BE STARTED

B TWO POSSIBLE TIME INTERVAL MEASUREMENTS OF A SINGLE COMPLEX WAVEFORM

70.38

Figure 8-42. —Time interval waveforms.

d-c at 0.5 amp for use by other equipment. The set can be used for laboratory frequency measurements and to drive precision timing devices such as a time comparator.

TELETYPE DISTORTION ANALYZER

There is an ever increasing need for more rigid radio teletypewriter transmission quality control in the operations of communications systems facilities. In the past there has been a tendency toward more rigid tolerances in equipment manufacture, with only normal emphasis on the maintenance of rigid control of equality of transmission in the operating system. The trend toward higher transmission speeds, and the introduction of new modes of operation into the system, have not only emphasized the need for better quality control, but have caused most of the equipment formerly used for analysis of signals to be obsolete, or at least inadequate. The first step toward improvement in the quality of transmission is the analysis of signals. Only by the analysis of signals can it be determined what is necessary to improve the quality, or check on actions to determine whether or not they actually produce an improvement. The AN/GGM teletype test set is considered capable of meeting these requirements for signal analysis for all teletypewriter systems presently in use, and in addition can be readily adapted to any new modulation rates up to 600 baud.

The design philosophy of the AN/GGM-1 is based on a modular concept and consists of the following plug-in units.

	Military Nomenclature	Stelma Model Number
Digital Distortion Analyzer	TS-1512/GGM	DD-5
Test Pattern Generator	SG-431/GGM	PG-105
Oscilloscope	OS-119/GGM	DSS-5
Time Base Generator	SG-430/GGM	TBG-5
Power Supply	PP-2971/GGM	PS-5

The above AN/GGM-1 equipments mount in a standard 19" wide rack for fixed station use. All interconnecting cables are provided with the equipments.

The complete system is also available mounted in an equipment cart, for ease of movement around the communications center.

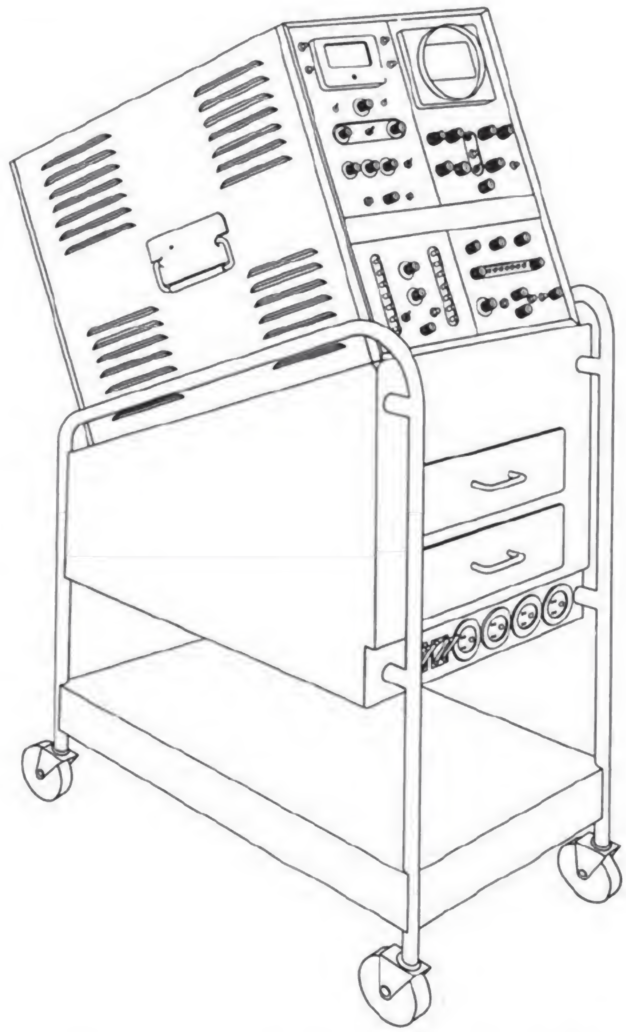


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Figure 8-43.—Teletypewriter Test Set, AN/GGM-2.

This mobile DAC-V has been nomenclatured AN/GGM-2 (figure 8-43).

DIGITAL DISTORTION ANALYZER, TS-1512/GGM (STELMA DD-5)

The Digital Distortion Analyzer, TS-1512 (figure 8-44) is a teletypewriter test set that provides an entirely new approach to the art of signal distortion analysis. By the use of digital computor techniques and solid-state devices, the TS-1512 should provide a degree of long-term accuracy and reliability not possible with analogue electron tube methods.

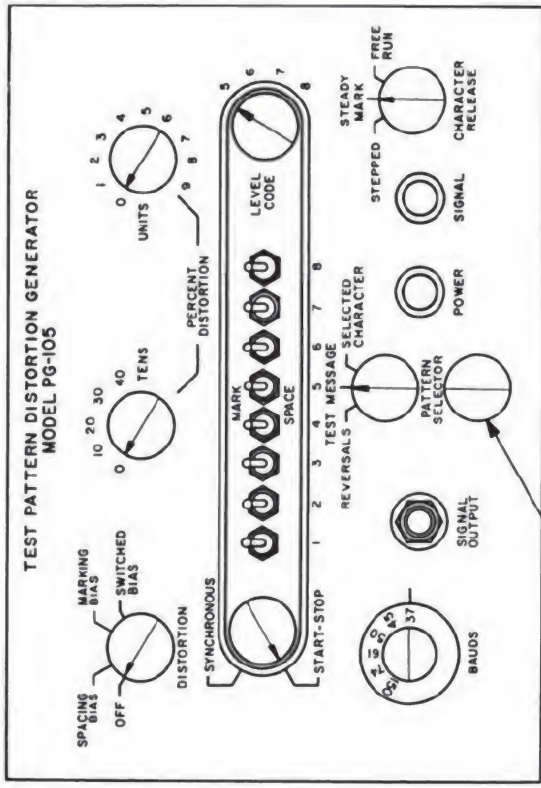

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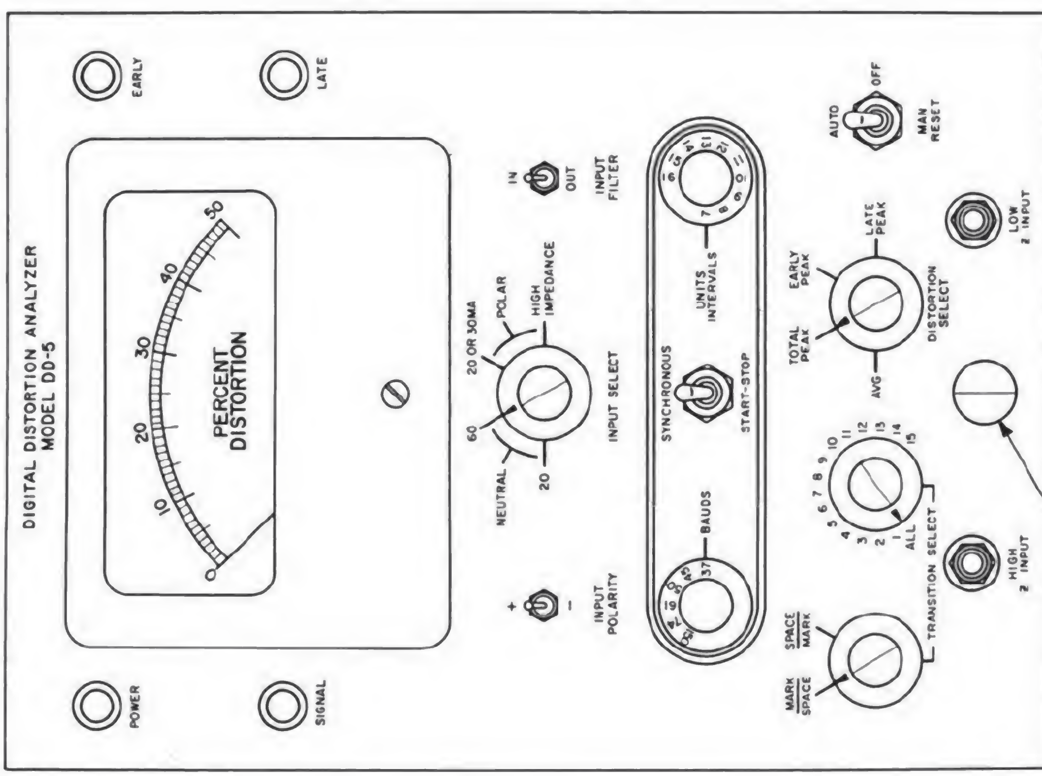
Figure 8-45.—Test Pattern Generator, SG-431/GGM.



1-323

Figure 8-44.—Digital Distortion Analyzer, TS-1512/GGM (STELMA DD-5) Front panel.

In addition to providing a comprehensive distortion analysis of all signal transistions, the TS-1512 permits an operator to make accurate, unambiguous measurements by reading a number on a meter.

The unit is as applicable to isochronous signals (synchronous systems) as to start/stop signals and will accommodate any speed to 600 baud. Timing signals are provided by the SG-430/GGM Time Base Generator. The SG-430/GGM permits the addition or change of any modulation rate by replacing a plug-in printed circuit card. In this manner, additional modulation rates can be accommodated, as the station requirements demand, with no change in TS-1512.

Some of the most important characteristics of the TS-1512 are listed below:

(1) Measures Peak Distortion and Holds Reading Indefinitely Until Reset.

One of the most important features of the TS-1512 from the operator's viewpoint, since it allows the operator to make a positive reading of peak distortion on a disturbed circuit, and eliminates the confusion of pips or dots continuously bouncing around on an oscilloscope screen.

(2) Provides Complete Analysis of Signal Distortion with Readings Displayed on a Large Front-Panel Meter.

The front-panel controls of the TS-1512 permit the analysis of every transition and every element of the character – either individually or combined. There is no type of distortion that can escape measurement on the meter.

(3) Accommodates Any Baud Rate Up to 600 Bauds.

The TS-1512 operation is independent of baud rates. Baud rates may be changed or added without affecting the Analyzer in any manner.

(4) Measures Start/Stop and Synchronous Signals with Equal Accuracy. Automatic Phasing Provided on Synchronous Signals.

The TS-1512 contains a digital servo which automatically locks in on the incoming synchronous signals. No adjustments are necessary; the operator does not manually ride the speed control. Accurate measurements of synchronous distortion are made independently of operator judgement or training.

(5) Provides Long-Term Reliability and Accuracy.

Accuracy is not dependent upon linearities, dc levels, charging capacitors, etc., due to the exclusive use of digital techniques and transistor switching circuitry. This also avoids the complex adjustment requirements found in measuring instruments employing analogue techniques.

(6) Assures Increased In-Service Time and Decreased Maintenance.

Only two types of adjustments are used in the DD-5 (input trigger and meter) – both are internal and factory set. The TS-1512 has no other operating or maintenance adjustments.

(7) Enables Unskilled Operators to Make Accurate, Dependable Measurements (Start/Stop or Synchronous).

Because distortion measurements are displayed on the large front-panel meter, the need for interpretation of the display, by the operator, is eliminated. The untrained operator need only record the reading on the meter.

(8) Permits Accurate Recording of Circuit Conditions for Station Supervisors.

Because of the certainty of the meter indications, distortion readings are not dependent upon the judgement of individual operators, as in the case of oscilloscope displays. An external pen recorder can be connected to the TS-1512.

(9) Meter Indications of the TS-1512 May Be Obtained Remotely in the Station.

The application of the unit may be extended to a number of remote positions in the station by the use of up to six extension meters.

TEST PATTERN GENERATOR, SG-431/GGM (STELMA PG-105)

The Test Pattern Generator, SG-431/GGM, (figure 8-45) is a solid-state test pattern generator that transmits the "Quick Brown Fox" test message, repeated characters, or reversals. The test patterns may be transmitted with zero distortion or with any amount of distortion from 0 to 49%, in steps of 1%.

Spacing bias, marking bias, or switch bias may be transmitted at all baud rates with an overall accuracy within 2%.

The SG-431 transmits an 80 character test sentence. The last seven characters, after the "fox" sentence are optional and may be conveniently programmed into the unit in the field (station call letters, etc.).

In addition, the Generator may be programmed to transmit any repeated character by means of front panel switches. The character coding may contain 5, 6, 7, or 8 intelligence bits for start/stop transmission.

An additional function provided is the ability to transmit repeated synchronous patterns up to 8 bits in length in any combination of marks and spaces.

The unit is capable of transmitting test signals in either a "free-running" or "stepped" mode by on-line synchronous equipments. The test sentence transmitted is compatible with isochronous signals for transmission over synchronous links.

As in the case of the TS-1512 Test Set, the SG-431 is independent of baud rate and receives its timing signals from the Time Base Generator, SG-430.

OSCILLOSCOPE,
OS-119/GGM (STELMA DSS-5)

The Oscilloscope, OS-119/GGM, (figure 8-46) is an oscilloscope specially designed for viewing data/radio teletypewriter signals.

It provides an automatic means of viewing radio teletypewriter signals, while traffic is being transmitted, by selecting a single character and blanking the ones that follow.

By presenting the selected character on a five-inch long-persistence cathode-ray screen, the oscilloscope permits the operator to view the signal on working circuits with an accuracy and clarity not possible with ordinary oscilloscopes.

The OS-119 receives its sweep timing signals from the TS-1512 Test Set and is designed to be used in conjunction with the TS-1512. When the TS-1512 is set by an operator to analyze individual segments of a signal, the selected segments are intensity modulated, automatically, on the OS-119 screen. In addition, the input trigger operating points of the TS-1512 are displayed on the OS-119 screen as intensity modulated dots.

The OS-119 may also be used with its own internal sweep as a normal oscilloscope to view transistions, crossovers, etc.

A front-panel control on the OS-119 provides options for selecting a single character and blanking the subsequent characters for up to 1-2 seconds, or blanking all of the following characters after selection of the character to be viewed. The character selected to be viewed is chosen at random. Where special analysis is required, a camera can be synchronized with the character selection. Specific characters can then be recognized and the wave shape analyzed.

TIME BASE GENERATOR,
SG-430/GGM (STELMA TBG-5)

The Time Base Generator, SG-430 (figure 8-47) provides timing signals to the TS-1512 Test Set and SG-431 Test Pattern Distortion Generator for all baud rates. The SG-430 provides up to twelve crystal-controlled transistor oscillators with a stability of 1 part in 10,000 per day.

The oscillators are constructed on plug-in printed circuit cards; each card is associated with a specific baud rate for rapid change or replacement. Visual and audible alarms are provided upon oscillator output failure of any card. Since each plug-in card provides the timing signals for a specific baud, the SG-430 may be ordered with any number of cards up to 12 each. Thus, if six different rates are required, only six plug-in cards need be ordered. Additional cards can be obtained as baud rate requirements change or increase.

Provision is made for including a variable baud rate oscillator adjustable from 30 to 100 bauds by means of a front panel control. Coaxial connectors are provided at the rear of the SG-430 to permit insertion of an external time standard.

Each crystal oscillator provides sufficient power to drive up to twenty-five AN/GGM-1 submodules which may be remotely located in the station.

POWER SUPPLY,
PP-2971/GGM (STELMA PS-5)

The Power Supply, PP-2971/GGM (figure 8-48) supplies all power required for the TS-1512 Test Set and SG-431 Test Pattern Distortion Generator and the SG-430 Time Base Generator. The OS-119

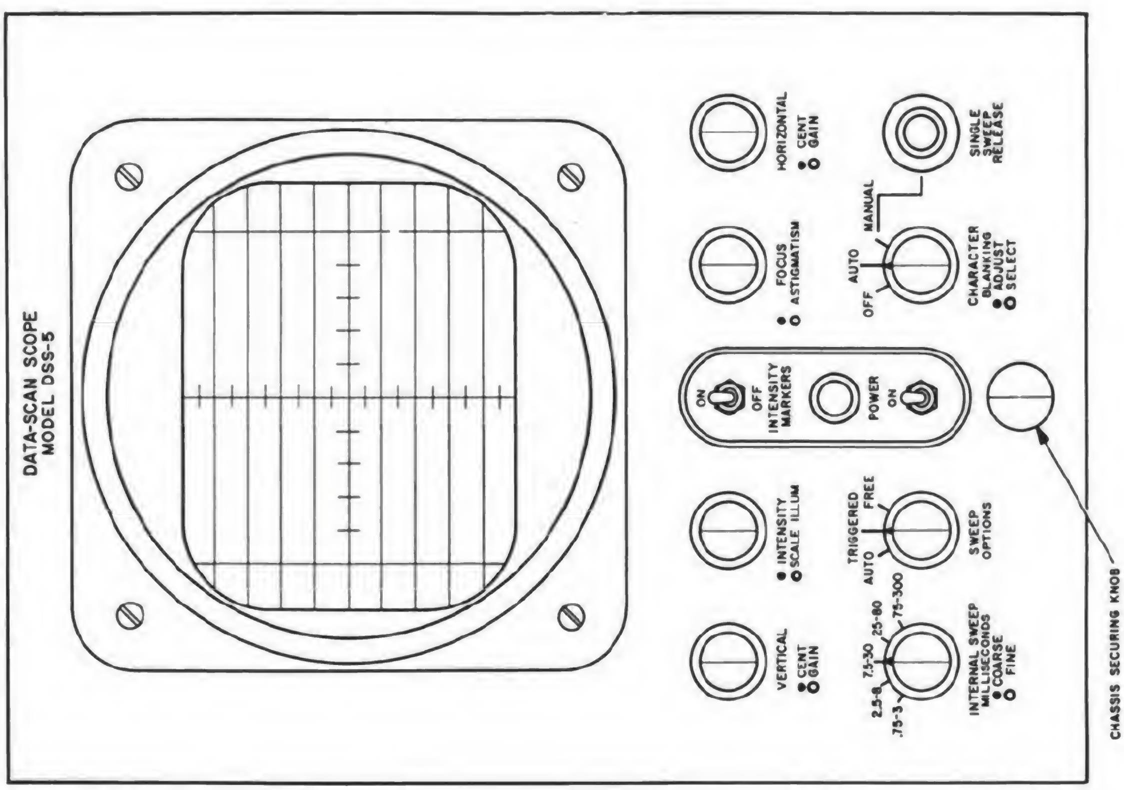


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Figure 8-46. —Oscilloscope, OS-110/GGM (STELMA DSS-5) Front panel.

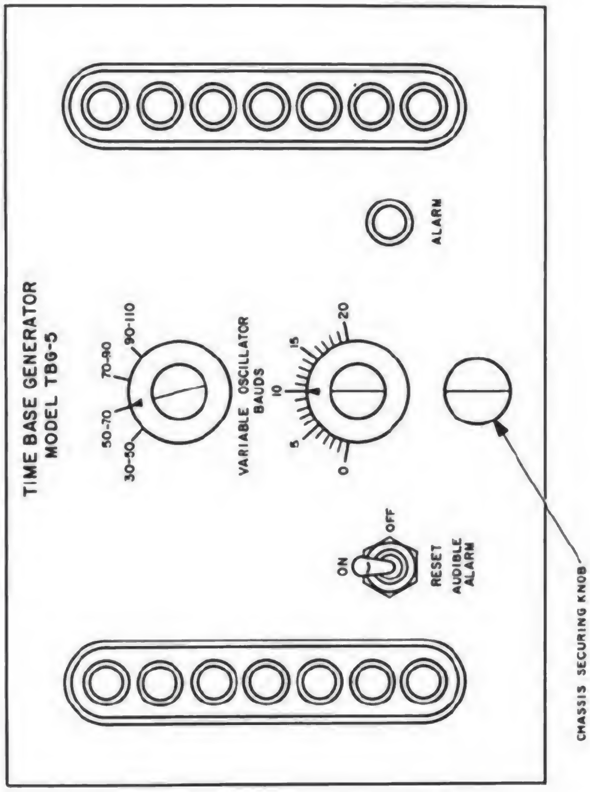

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Figure 8-47. —Time Base Generator, SG-430/GGM (STELMA TSG-5) Front panel.

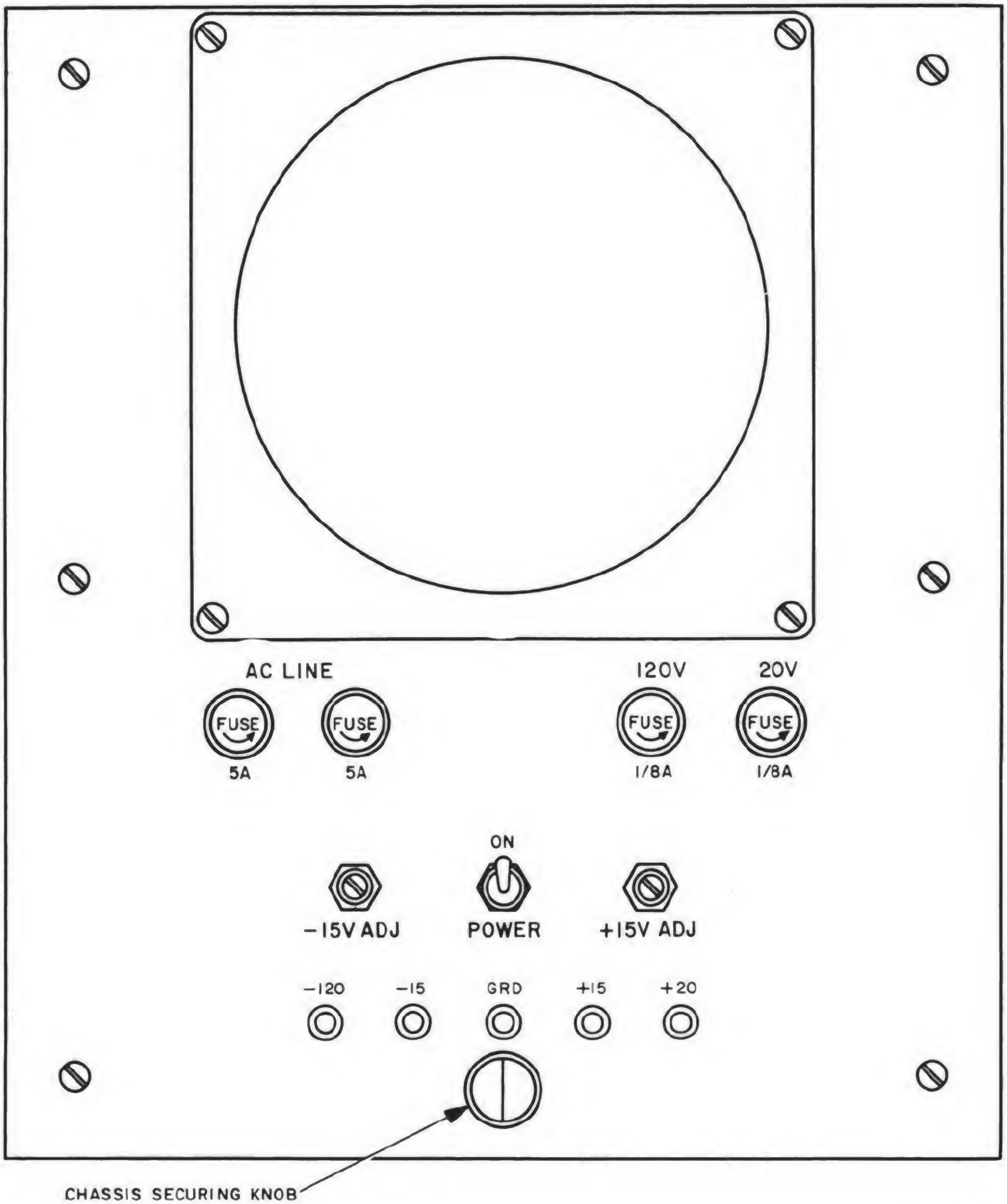

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Figure 8-48.—Power Supply, PP-2971/GGM (STELMA PS-5) Rear panel.

Oscilloscope has its own self-contained power supply.

The PP-2971 is a solid state power source that provides + 15 volts d-c and - 15 volts d-c, regulated to within 1% of the maximum load of 30 watts. It also provides 6.3 volts a-c. Power input is 115 volts ± 10%, 50/60 cycles, single phase.

The PS-5 does not occupy front panel space. It is a plug-in module inserted into the Rack Shelf Adapter behind the TS-1512 Test Set.

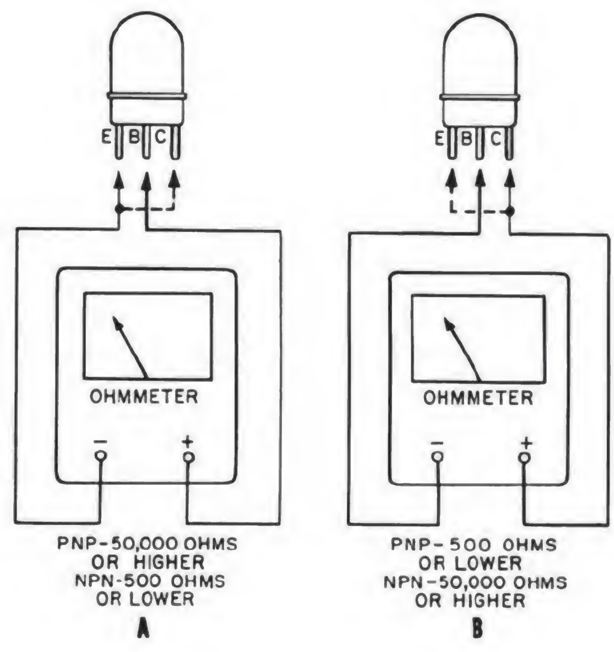
TRANSISTOR TESTER

Transistors may be tested "in-circuit" or "out-of-circuit." Also, the tests may be either d-c, where the measurements are made by d-c test equipments, or a-c where there is an a-c input to the base circuit and an output from the collector circuit. A-c measurements may be made either in-circuit or out-of-circuit. D-c measurements can be made out-of-circuit only; otherwise, the measurements might be affected by equipment d-c or biasing voltages.

PRECAUTIONS TO TAKE BEFORE MAKING ANY TRANSISTOR TEST

1. Make sure that all power has been removed from the equipment under test before servicing, testing, or removing a transistor or transistorized assembly.
2. Before employing any test equipment, it should first be determined that the test instrument meets the requirements for the test and type of circuit.
3. Be sure that any line-powered test equipment has been properly grounded to the chassis of the equipment under test.
4. Check the test equipment circuit on all ranges, to be sure that it does not pass more than 1 milliampere of current through the transistorized circuit under test. More amperage cannot safely be used for testing most transistor circuits. Use a low-resistance milliammeter in series with the test leads for this check.
5. Before making any measurements, be sure that any voltage applied is of the correct polarity for the circuit under test. Do not depend on the indicated polarity; use a voltmeter in series with the test leads for this check.
6. Do not trouble-shoot transistor circuits by the shorting-to-ground method. Short circuits of any kind will damage a transistor. Extreme care must be taken to avoid these shorts—use special insulated test probes to prevent accidental shorting.

A rough check may be made on a transistor by means of d-c tests that will determine its forward and backward resistances and also any leakages or shorts. Connections for these tests are shown in figure 8-49. With the positive ohmmeter lead connected to the base of a PNP transistor (figure 8-49A), a high-resistance reading (50,000 ohms or higher) should be obtained between base and emitter, and between base and collector. With the negative ohmmeter lead connected to the base of a PNP transistor (figure 8-49B), the resistance between the base and collector and between the base and emitter should be 500 ohms or less. If the same ohmmeter tests are made on an NPN transistor, the results will be reversed; that is, the high-resistance readings will be obtained with the negative ohmmeter lead connected to the base, and the low-resistance readings with the positive ohmmeter lead connected to the base. If the correct resistance readings are not



A — Base lead positive.
B — Base lead negative.

70.102

Figure 8-49.—Transistor resistance testing.

obtained from the ohmmeter test, the transistor should be replaced.

This type of test may also be used for determining the type of a transistor, PNP or NPN, when its type is unknown. With the test connection as in figure 8-49A, a high-resistance reading (50,000 ohms or higher) shows that it is a PNP type; a low-resistance reading (500 ohms or less) shows that it is an NPN type.

In checking transistors, there are two basic tests—collector current leakage and transistor gain, or amplification.

Age and exposure to higher-than-normal temperatures may develop greater-than-normal collector leakage current, generally designated as I_{CO}. Such current is greatly dependent on ambient temperature; thus extreme care must be taken to see that this temperature remains under control. One positive sign of a defective transistor is instability of I_{CO}. When there is a tendency for the leakage current to climb slowly of its own accord, it is quite evident that the transistor is defective. A high leakage current indicates a deterioration of the transistor, and is usually accompanied by lower gain.

As illustrated in figure 8-50, collector leakage current tests may be made in two ways. Figure 8-50A shows the connections for checking the leakage current in the collector-emitter circuit, with the base open. Figure 8-50B shows the connections for checking the leakage current in the collector-base circuit, with the

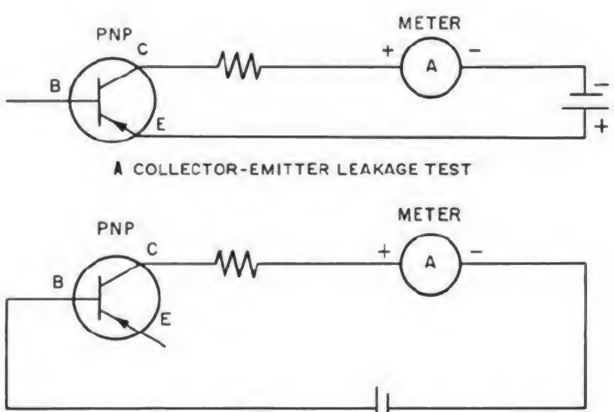


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Figure 8-50.—Collector leakage current test, schematic diagram.

emitter open. Any contamination on the surface of the transistor, or a short circuit within, will produce a high current reading on the meter.

In comparing the two test arrangements, the only advantage of the test in figure 8-50A is that, since the collector-emitter circuit is of low resistance (possibly about 1000 ohms), normally there will be sufficient leakage current to be read on a milliammeter, which is nearly always available. However, the test outlined in figure 8-50B requires a much more sensitive instrument, and is to be preferred if a suitable instrument is available. Since the transistor is reverse-biased (PNP-type transistor with negative terminal of battery toward collector), the reverse current is very small. It is a high-resistance circuit (on the order of 50,000 to 70,000 ohms), and the leakage current is usually no more than 10 to 15 microamperes. Such small currents are best measured on a transistor test set, which is usually provided with a sensitive microammeter.

TEST FOR BETA

Since one of the primary functions of a junction transistor is amplification, one of the basic tests, in addition to the collector leakage test, is a check of gain (or amplification), designed "beta." The gain test is a measurement of the change in collector current for a small change in the base current.

All of the current in a transistor is supplied by the emitter, of which more than 90 percent goes to the collector and the remainder to the base. Where, for example, 95 percent of the current goes to the collector and 5 percent to the base, then beta = 95/5 = 19. A beta of 19, then, means that for any change in current in the base, the change in the collector will be 19 times as great.

To measure beta, approximately correct results can be obtained by removing the transistor from the equipment and using d-c test methods. Better results can be obtained, however, when the test is made under operating conditions, using a-c test methods. This test can best be accomplished by use of a transistor test set designed specifically for the purpose.

TYPICAL TEST SET

Transistor Test Set TS-1100/U (figure 8-51) measures the amplification, or beta, of the

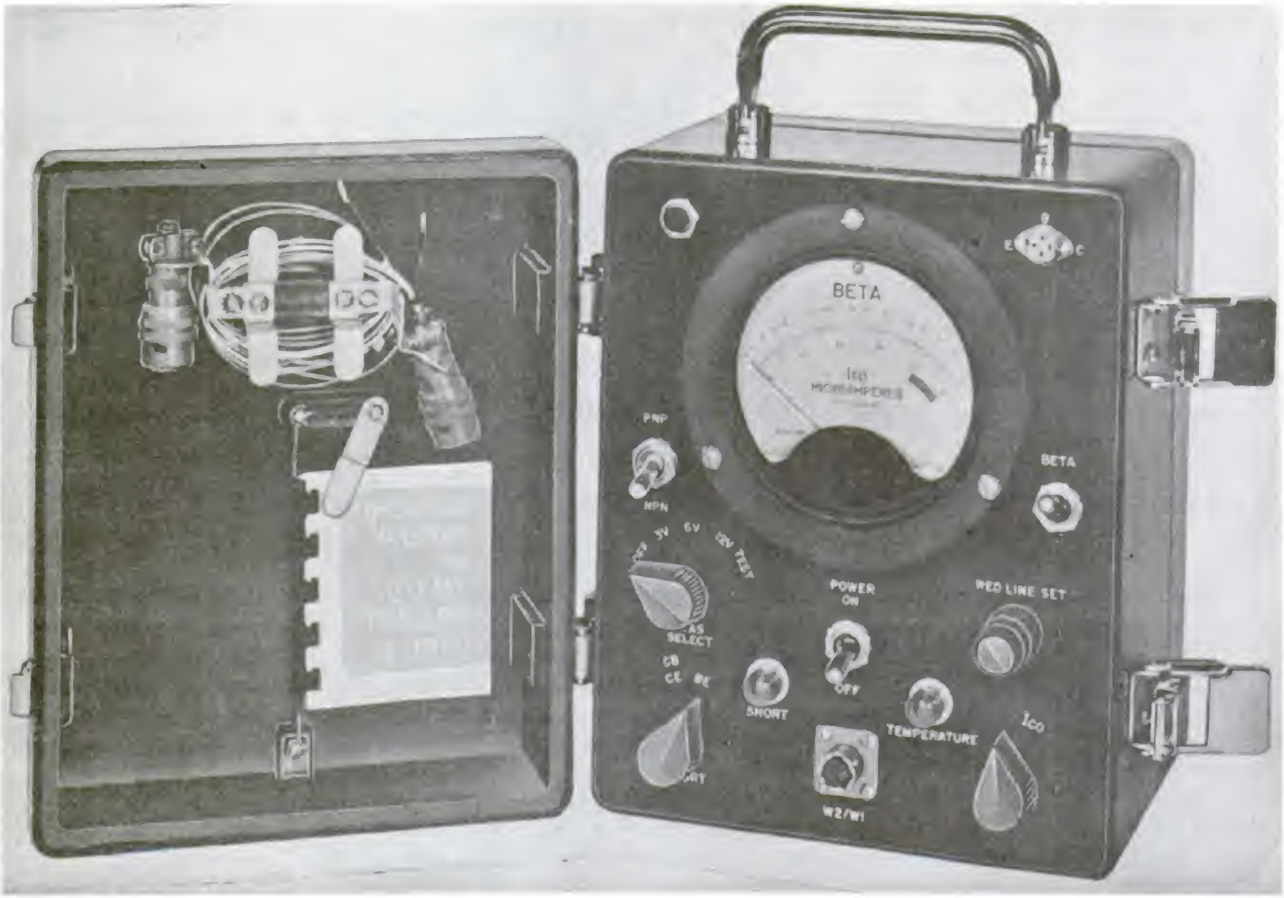

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Figure 8-51.—Test Set, Transistor TS-1100/U.

transistor without the need for removing the transistor from the circuit. In addition, it will test for collector leakage current, with the transistor out of the circuit, and it will also test for shorts. The test set is portable, and operates on dry cells which have a life expectancy of approximately 1000 hours.

The many types of transistor base connection arrangements require that the leads be properly identified to secure correct hookup to the tester. The TS-1100/U test socket arrangement is compatible with some transistor types, but not all types. If the leads are long enough, it is generally possible to effect proper hookup by bending them. If the leads are too short, it will be necessary to use the test cable and alligator clips provided with the tester. In all cases, however, the transistor leads should be identified and then matched up with the tester connections.

The great advantage of the TS-1100/U lies not only in its accuracy and simplicity, but also in its use of a-c as the testing current. This eliminates interference from any d-c currents and voltages that may be present and permits measurement of the gain of a transistor in-circuit, thus making it unnecessary to unsolder or disconnect the transistor for this test. This is particularly advantageous where the transistor is mounted on a module printed wiring board.

The a-c testing current is provided by means of a built-in oscillator and amplifier. To avoid possible interference from other frequencies, the amplifier is sharply peaked for a single frequency, 2250 cycles per second. The

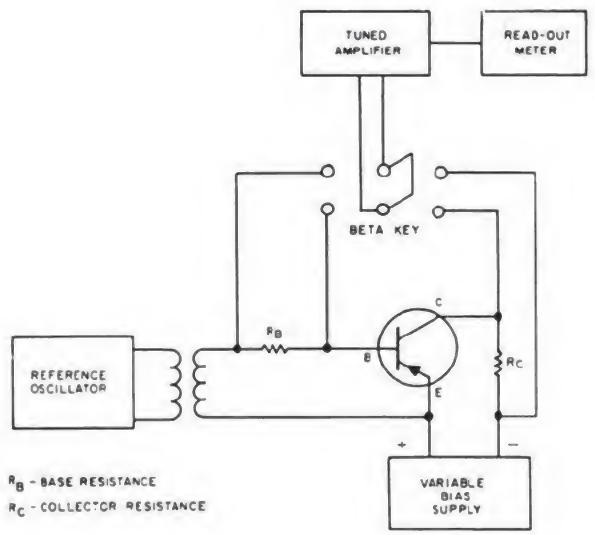

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Figure 8-52.—Measuring beta, using transistor.

test current is then rectified and read on a microammeter which has a full-scale deflection of 50 microamperes. The test is also provided with a variable bias supply. The method of determining beta for a given transistor is shown in figure 8-52. When the proper adjustments are made according to the instructions in the instruction book, the value of beta will be indicated directly on the meter.

TS-1100/U is also designed to measure collector leakage current, I_{CO}, which is read directly on the meter. The circuit arrangement is shown in figure 8-53. The technical manual for the test set provides information concerning the collector bias to be applied for a particular transistor and the maximum permissible collector leakage current.

However, since this current is d-c, the reading may be affected by other d-c potentials in the circuit. For this reason it is necessary to remove the transistor from the circuit in order to obtain an accurate measurement of collector leakage current.

The test set is also equipped to indicate a short between any two of the three elements of the transistor under test. With the transistor in-circuit, it will also indicate a short if the circuitry between any two of the transistor elements has a resistance of 500 ohms or less. To determine whether the short is in the transistor itself or in the associated circuit, it is necessary to remove the transistor from the circuit.

The test set has the following additional features: a switch marked PNP-NPN, which selects the proper bias polarity for the type of transistor under test; a temperature alarm indicator lamp, which will light when the ambient temperature surrounding the equipment exceeds 50° C; and a switch marked TEST, which checks the test set battery output.

In conjunction with the transistor test set, multimeters, when used for voltage measurements should have a sensitivity of 20,000 ohms per volt or better on all voltage ranges. Meters with a lower sensitivity will draw too much current from the circuit under test when used in their low-voltage ranges. A VOM (20,000 ohms-per-volt) or an electronic voltmeter (VTVM) with an input resistance of 11 megohms or higher on all voltage ranges is preferred. However, a VTVM should be used with an isolating transformer between the VTVM and the power line.

Ohmmeter circuits which pass a current of more than 1 milliampere through the circuit under test cannot be used safely in testing transistor circuits. Many electronic voltmeters have ohmmeter circuits which exceed this safe value of 1 milliampere. High-sensitivity multimeters often are shunted on ohmmeter ranges, so that they also pass a current of more than 1 ma through the circuit

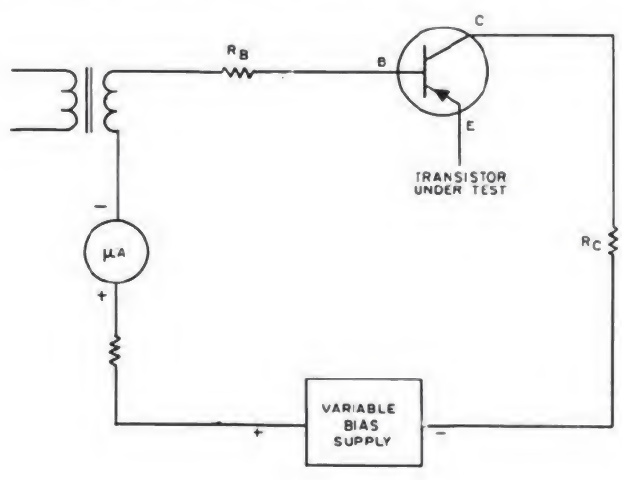

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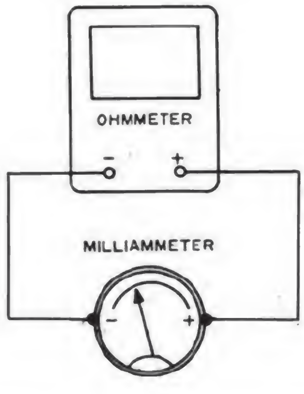
Figure 8-53.—Measuring collector leakage current, Ico, using Transistor Test Set TS-1100/U.



70.43
Figure 8-54.—Measuring current passed by ohmmeter.

under test. Before using any ohmmeter on a transistor circuit, the circuit it passes under test should be checked on all ranges. Do not use any range which passes more than 1 ma. To check the current, adjust the ohmmeter for resistance measurements; then connect a milliammeter in series with the test leads (figure 8-54), and observe the indication on the milliammeter. The meter used should have a low resistance such as contained in Multimeter TS-352A/U or equivalent.

TESTING CRYSTAL DIODES

CT M's usually will be working with three types of crystal diodes: General-purpose germanium and silicon diodes, power silicon diodes, and forward and reverse high-frequency silicon diodes (commonly called mixer crystals).

A sectional view of a typical germanium crystal diode is illustrated in figure 8-55. A number of different types of crystal diodes are illustrated in part B. Germanium diodes are usually enclosed in a plastic or glass cylindrical case with pigtail connections.

The cathode end, usually marked with a painted band or other distinctive marking, contains a small crystal of N-type germanium. A thin catwhisker wire makes a point contact with the crystal. Electrons will flow easily from the germanium into the catwhisker; this makes the catwhisker the anode and the crystal the cathode. Some diodes of this design are being made with silicon crystals in place of the germanium. Silicon power diodes are just beginning to be produced. Their outputs and operating temperature are considerably above those of germanium.

Germanium diodes, such as the 1N34A or 1N69, are used for a wide range of applications, such as video, audio, and pulse circuits. Many are used as detectors in radio and television equipment, and as mixers at frequencies up to 900 megacycles.

Mixer crystals, such as the 1N21 or 1N23, are designed for microwave detection and mixing. These are very carefully made diodes, with low-loss ceramic barrels and machined and gold-plated brass tips and bases for close fits in waveguides and coaxial fittings. Two 1N23B silicon crystal diodes are shown in figure 8-56; a sectional view is also shown.

A small crystal of almost pure silicon acts as a P-type semiconductor. Electrons will pass easily from the catwhisker to the silicon, making, in effect, the base the anode and the tip the cathode. Mixer crystals of this type are available for use with frequencies from 1000 to 10,000 megacycles.

Diodes for 10,000 megacycles and above are usually of the coaxial type, as shown in fig. 8-57.

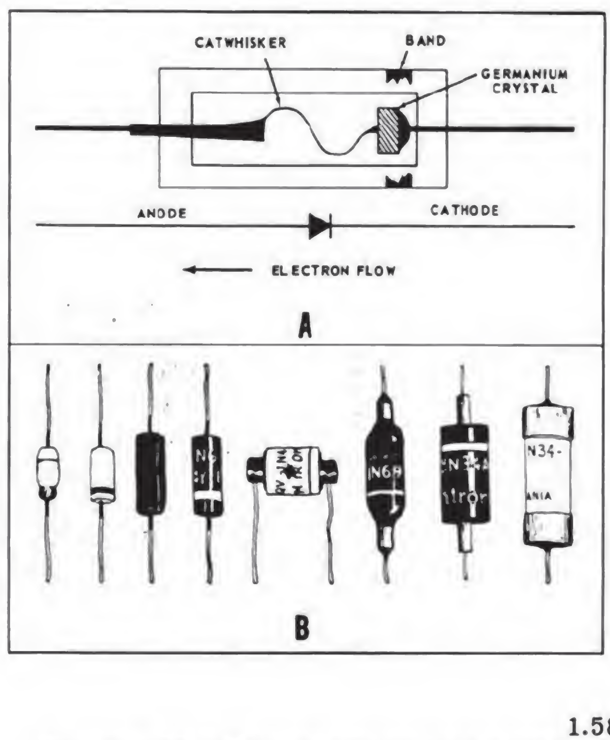


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Figure 8-55.—Typical germanium crystal diodes.

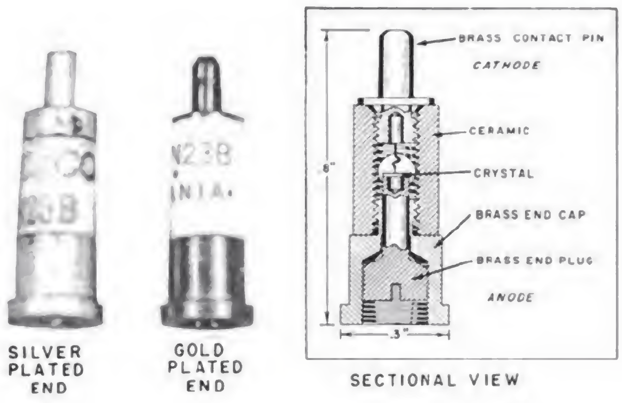

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Figure 8-56.—Cartridge-type silicon crystal diodes.

Reverse crystal mixers (for example, the 1N23CR) cause considerable confusion. Reverse polarity crystals (figure 8-58A) are identical in characteristics to the ordinary type (figure 8-58B) whose number they carry. Thus, a 1N23CR is identical electrically to a 1N23C except for the reversal of polarity. The crystal in the reverse type (1N23CR) is fastened to the tip, making the tip the anode and the base the cathode. In the ordinary type the crystal is fastened to the base, making the base the anode and the tip the cathode.

The properties of the crystal rectifier depend on the pressure, the contact area, the place of contact, etc. This has been carefully adjusted at the factory and should not be upset by tampering with the set screw.

The area of the contact is very small, and if too much power is passed through the cartridge, the resulting heat will damage it, and the crystal rectifier will be impaired. The crystal rectifier may be damaged, for example, by a static discharge through it. If the CT M holds one end of the crystal and touches the equipment with the other end, any static charge on his body will discharge through the crystal mixer. He should first touch his finger to the mixer chassis and then insert the crystal rectifier in its holder, as illustrated in figure 8-59.

A crystal may also be damaged by exposure to a string r-f field. Therefore crystal rectifiers must be kept in a metal box or wrapped in metal foil except when in use or being tested.

In the equipment in which the crystal rectifier is used, it is normally protected by a TR tube is to place a short across the line leading to the crystal rectifier by means of gas breakdown in the tube during the firing of the main transmitter pulse. The returning signal, or echo, is much smaller than the transmitter pulse and does not cause a breakdown. It therefore comes through to the crystal rectifier. During the main pulse, some power does leak through the TR tube because it is not a perfect short. However, this power is normally small enough not to damage the crystal.

It is obvious that if the TR tube is defective function properly, the crystal rectifier may be damaged. Improper functioning may be due either to the fact that the TR tube is defective or there is incorrect TR tuning (if tuning adjustments are provided).

Another possible cause of crystal damage is a distortion of the pulse shape of the modulator. If the pulse has a sharp peak at the beginning (instead of the usual square shape), much more power will come through the TR tube than for a square pulse of equal energy (because of insufficient time for the blocking action to occur)

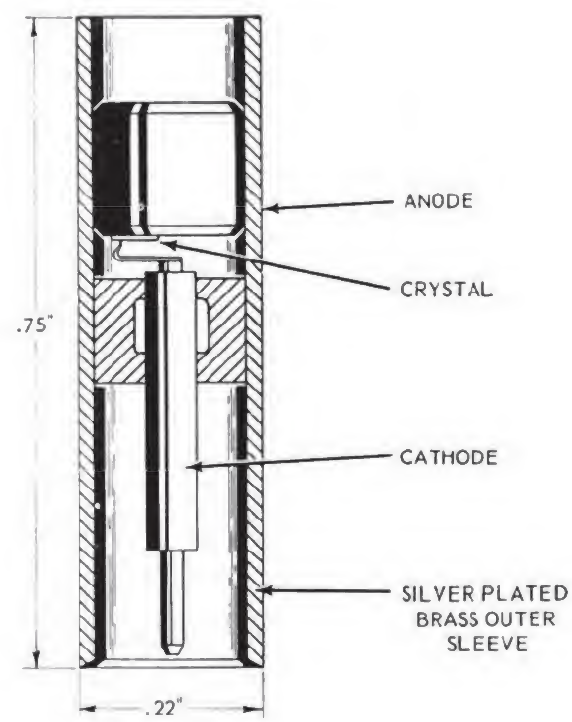

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Figure 8-57.—Sectional view of coaxial silicon crystal diode.

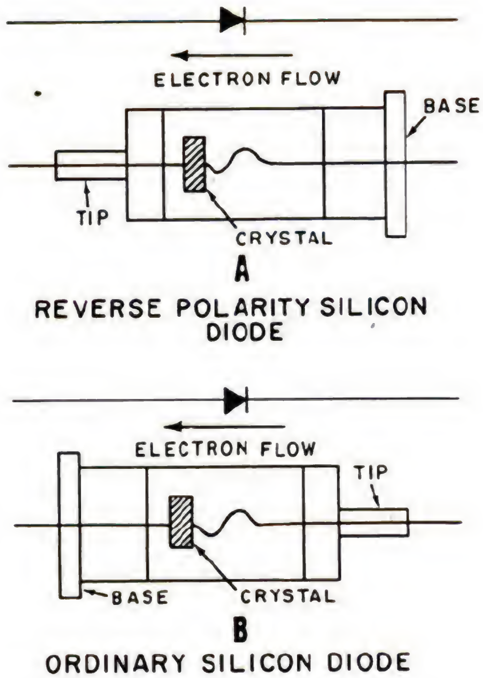

Figure 8-58. —Ordinary and reverse-politary silicon diodes.

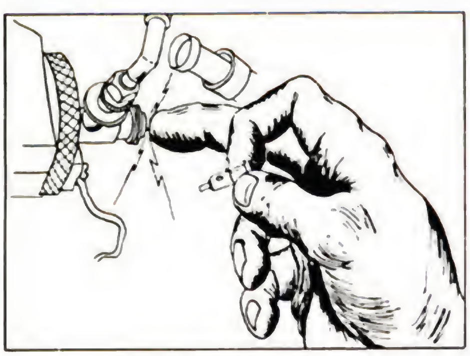

Figure 8-59. —Reinserting crystal rectifier in mixer.

although the TR tube may be operating normally. Faulty TR operation and distorted modulator pulses are the two main causes of crystal rectifier impairment. Continued impairment of good crystal rectifiers is an indication that

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Figure 8-60. —Front view of Model TS-268/U Crystal Rectifier Test Set.

the TR tube and the modulator should be checked.

The deterioration of the crystal rectifier in a receiver produces an increase in noise or a decrease in signal, or both, assuming that other factors (for example, receiver gain, transmitter strength, and target distance) remain the same. Such a change results in a decrease in the signal-to-noise ratio; and it is the signal-to-noise ratio that determines the over-all merit of a receiver. Other possible causes of a low signal-to-noise ratio are improper functioning of the first IF stage (pre-IF), or excessive losses between crystal and first IF stage (such as in the cable or connectors), or improper tuning of the local oscillator.

If produced gradually, the impairment of a crystal rectifier is quite difficult to notice. One method of detecting the impairment is to

Table 8-3. —Crystal Rectifier Limits.

Crystal Rectifier Types	Backward-to-Forward Resistance Ratio (minimum)	Back Current in ma (maximum)
1N21	10/1	0.40
1N21A	10/1	0.175
1N21B	10/1	0.125
1N23	10/1	0.4
1N23A	10/1	0.3
1N23B	10/1	0.175

compare the operation of the crystal rectifier with that of a new one. If, under the same operating conditions, the noise is less or the signal is greater with the new crystal, the old crystal is probably impaired. However, if the crystal rectifier current remains unchanged, it does not necessarily mean that the crystal rectifier is unimpaired.

To test a crystal rectifier properly and completely is an elaborate matter and requires precision test equipment. However, the crystal rectifier test sets (for example, Model TS-268/U) supplied to the Navy CT M's are sufficiently accurate for field use.

A front view of Model TS-268/U Crystal Rectifier Test Set is shown in figure 8-60. The limits (minimum forward-to-reverse resistance ratio and maximum reverse (back) current) established by laboratory tests are shown in table 8-3.

CHAPTER 9

SWITCHES, SWITCHING SYSTEMS, AND SYNCHROS

A basic understanding of switches and synchros and the functional use of switching systems and synchro systems is a necessity for the CT M. In general, methods of operation of electronic equipments are being simplified, while switching systems are becoming more complex. Therefore, in some instances, the switching systems used with electronic equipment are more difficult to understand than the equipment itself.

The Navy uses hundreds of different types of switches in (and associated with) electronic equipment. They are listed in the Navy Stock List of the Electronic Supply Office, Federal Supply Class 5930.

Switchboards make use of multisection switches that are not difficult in themselves to understand, but the entire switching function performed by switchboards, or by combinations of switchboards, may be somewhat involved. These switchboards are replacing the old-style plugboards (more commonly known as patch panels).

The technician should bear in mind that in many of the switching systems described there are a large number of possible circuit arrangements. In this chapter a great deal of simplification is employed; and, in general, only the less complex arrangements are included. However, enough basic information is included to give the CT M the necessary background for further study in the subject.

TYPES OF SWITCHES

Some of the more common types of switches used with electronic equipment are illustrated and described briefly in this portion of the chapter. There are many variations of each type of switch; however, only a few representative examples are included here.

TOGGLE SWITCHES

Representative examples of toggle switches are shown in figure 9-1. Part A shows a single-pole, single-throw (SPST) toggle switch, rated at 20 v and 20 amperes, and having 2 screw terminals. The schematic diagram is shown beneath the switch. This switch is used to open or close an electric circuit.

Part B shows a single-pole, double-throw (SPDT) switch, rated at 250 v and 1 ampere, and having 3 screw terminals. One of the uses

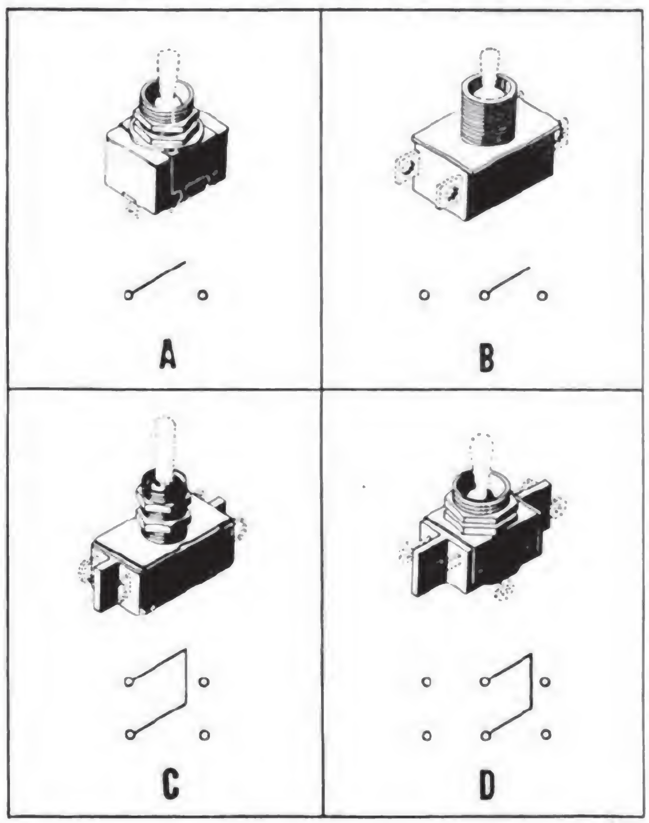

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Figure 9-1.—Toggle switches.

of this switch is to turn a circuit on at one place and to turn it off at another place. It is sometimes called a 3-way switch.

A double-pole, single-throw (DPST) switch is shown in part C. It has 4 solder terminals and is rated at 250 v and 1 ampere.

A double-pole, double-thros (DPDT) switch is shown in part D. It has 6 solder terminals and is rated at 125 v and 3 amperes.

The following types of switches are also used: 3-pole, single-throw (3PST); 3-pole, double-throw (3PDT); 4-pole, single-throw (4PST); and 4-pole, double-throw (4PDT) switches. The voltage ratings range from 20 v to 600 v, and the amperage ratings range from 1 ampere to 30 amperes.

PUSH SWITCHES

The contact arrangement of push switches is shown in figure 9-2A, and an example of a typical contact arrangement is shown in part B. The type and quantity of each basic form used to make up the contact assembly are determined from part A. Part B illustrates how the illustrations in part A may be used in a practical switch assembly. Thus, in part B the switch contains a total of three separate basic forms: two forms A, and one form C. The contact arrangement for this switch is therefore 2A1C. Obviously, there are many possible contact arrangements. For example, 1A, 1A1A, 1A1B, 2A, 2A1B, 1B, etc., are common.

A push switch employing a 2A contact arrangement is shown in figure 9-2C. It is rated at 250 v and 3 amperes.

WAFER LEVER SWITCHES

A wafer lever switch is shown in figure 9-3. It is a double-pole, triple-throw (DP3T) type of switch rated at 110 v and 0.150 ampere. A schematic diagram is shown beneath the switch. It locks in position and is nonshorting; that is, one circuit is opened before the next circuit is closed. In switches of this type the action may be locking or momentary, and the contacts may be shorting (for example, one circuit remains closed until an instant after the next circuit is closed; then it is opened) or nonshorting. Other contact arrangements are DPDT, 4PDT, and 6P3T.

LEVER PILEUP SWITCHES

One type of lever pileup switch is shown in figure 9-4A. As may be seen in the schematic illustration, it is a 2-position switch. There are 9 solder terminals, and the switch is rated at 48 v and 1 ampere.

A 3-position, 21-terminal switch is shown in part B, and a 2-position, 9-terminal switch is shown in part C.

(In the schematic diagrams the downstroke of the switch is designated by 2, the upstroke by 1, and OFF position by zero.)

Nearly a hundred types of lever pileup switches are available for various uses. They may have up to 75 terminals, and the associated switch contacts may be arranged in various ways.

In addition to lever pileup switches, rotary pileup switches (activated by a rotary motion) and the jacktype pileup switches (activated by the thrust of the plug) are used in automatic telephone systems.

KNIFE SWITCHES

Knife switches are essentially power switches; they will handle up to 500 amperes and up to 15,000 v. Figure 9-5A, shows a double-pole, single-throw (DPST) knife switch rated at 125 v and 30 amperes.

Part B shows a 4-pole, double-throw (4PDT) knife switch rated at 125 v and 100 amperes.

THERMOSTATIC SWITCHES

Thermostatic switches are designed to either open or close when the temperature reaches a certain value. A large number of different types of thermostatic switches are used by the Navy to control the temperatures in compartments and rooms, to regulate dampers, and to maintain constant crystal oven temperatures in electronics equipment; they are also used in many other heating and cooling applications. Switches of a given type may have different contact arrangements, be operated at different temperature ranges, or have different voltage or current ratings.

A large number of thermostatic switches employ a bimetallic strip as the active element. The basic operating principle is illustrated in figure 9-6A. One side of the bimetallic strip is brass and the other side is iron (other metals may also be used) welded to the brass.

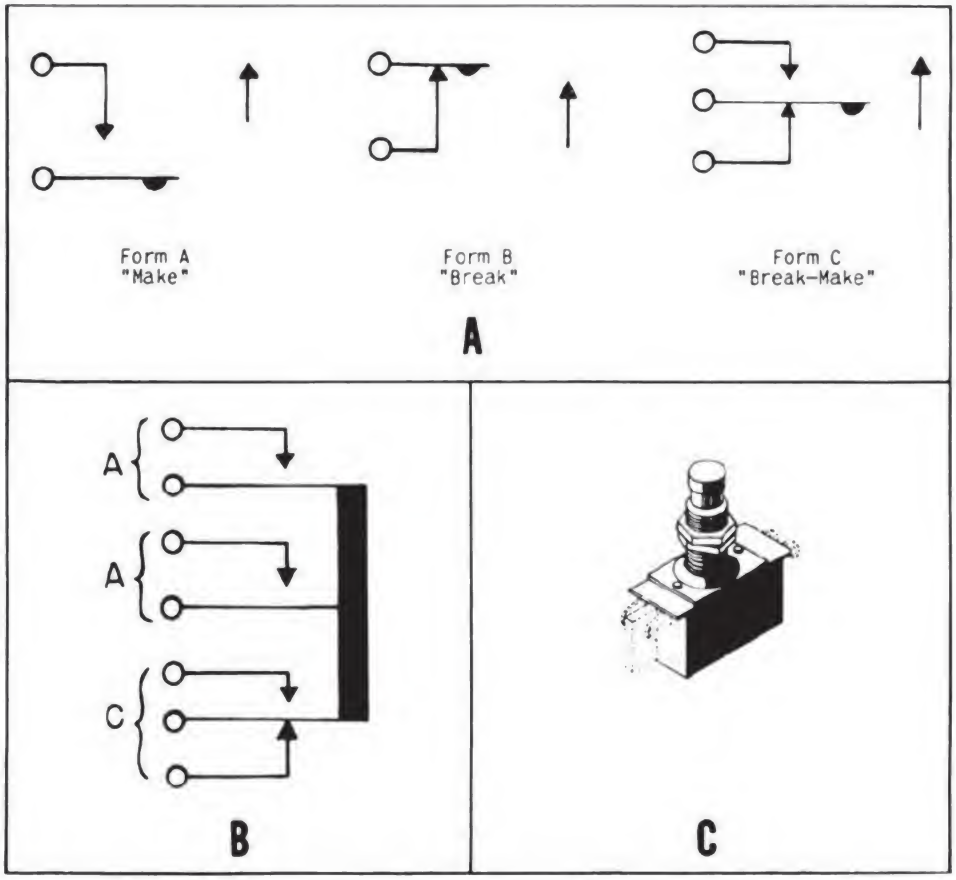

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Figure 9-2. –Push switches.

When the strip is heated, the brass expands more than the iron and the strip bends downward to open the switch contacts. Thus, power is removed from the load when a certain temperature is reached. Of course, the switch action may be reversed so that power is applied to the load when a certain temperature is exceeded. Although not shown in the figure, various refinements such as adjustments and snap action may be incorporated in the switch.

In mercury thermostatic switches the mercury itself completes the circuit as it expands upward between two metallic contacts. The basic operating principle is illustrated in figure 9-6B. When the temperature decreases, the mercury contracts and opens the switch.

In each of the illustrations, only the basic principle of operation is shown. Certain refinements are generally added.

Figure 9-6D, shows the thermostatic switch used in the crystal oven of one type of radio transmitter. The contact arrangement is for a single-pole, single-throw operation, and the switch is rated at 115 v and 0.75 ampere. The operating temperature is 170.6° F to 179.6° F, the temperature differential being 9°.

ROTARY PILEUP SWITCHES

Rotary pileup switches are so constructed that they open and/or close one or more electrical circuits; the contacts are arranged in a leaf, or pileup fashion and they are actuated by a rotary motion.

One type of rotary pileup switch is illustrated in figure 9-7. As may be seen in the figure, there are six terminals. When the armature is moved upward by the rotary motion of the switch cam, two circuits are opened and two other circuits are closed.

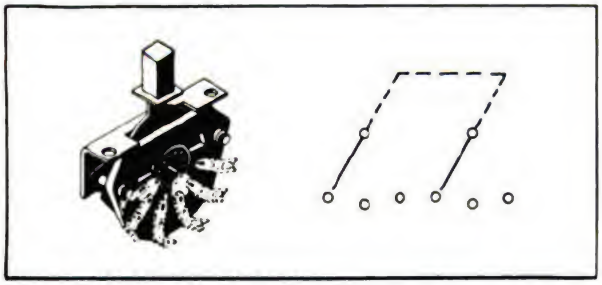

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Figure 9-3.–Wafer lever switch.

This type of switch has numerous applications in low-voltage signal circuits.

ROTARY SELECTOR SWITCHES

Rotary selector switches are used in a large number of electronic equipments. They are commonly made up of a number of sections, or decks, the number used depending on the complexity of the switching functions.

One deck of a rotary selector switch is shown in figure 9-8. The code letters are also included at the leads extending from the various terminals. Short clips are indicated by the letter, X. Dummy lugs are indicated by the letter, D. Nonshorting rotary teeth (or blades) are indicated by crossed lines. As used here the word "nonshorting" means that the width of the rotor tooth is less than the distance between adjacent contact clips. This means that as the rotor is turned, one circuit will be opened before the next one is closed. The shorting type is shown without the crossed lines. In this case the rotary tooth is wider than the distance between adjacent clips, and therefore as the rotor is turned, one circuit is closed before the preceding one is opened. Clips that are insulated from their associated lugs are indicated by the

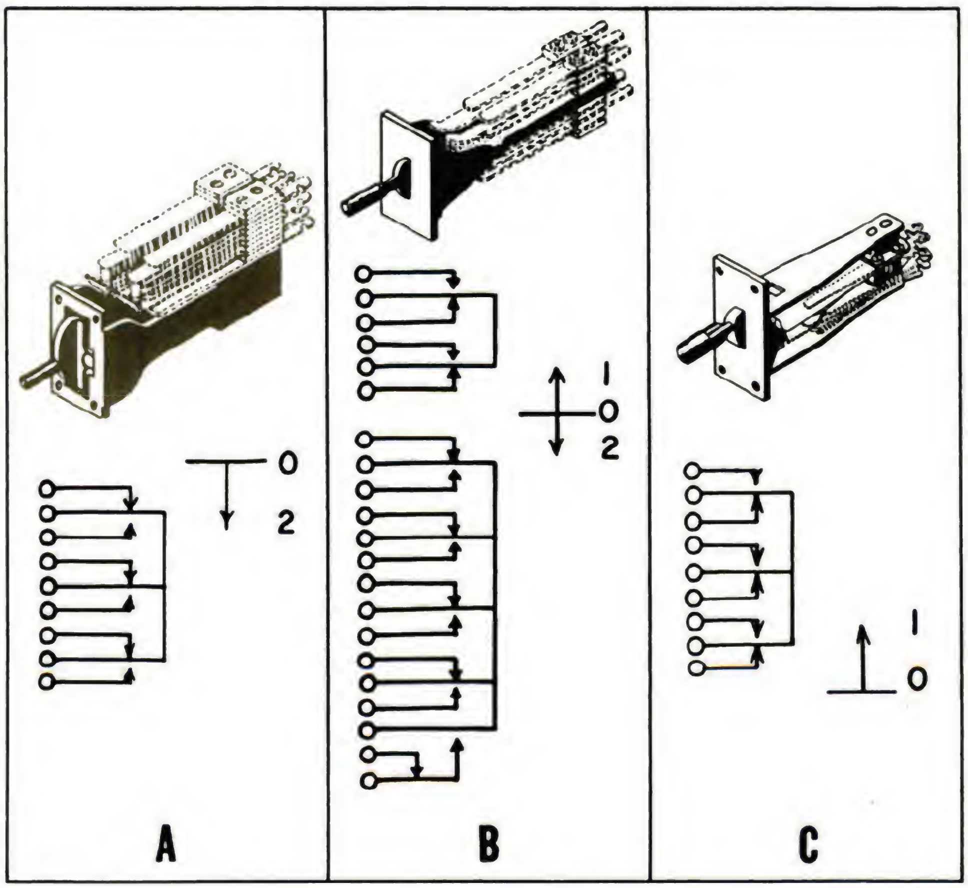

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Figure 9-4. –Lever pileup switches.

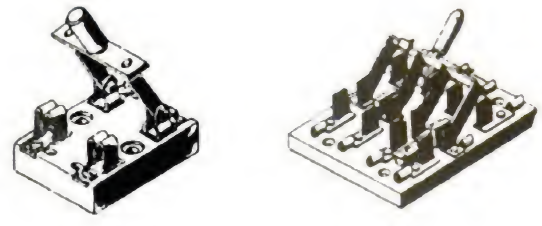

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Figure 9-5.—Knife switches.

letter, S; long clips thus insulated are indicated by the letters, YS. When a clip is thus insulated, the lug may be connected to a clip on the reverse side. A through electrical connection is indicated when the rotor (or a portion of it) is shown in black. This means that the section of the rotor so marked in the figure is connected through to a bottom rotor, not shown.

There are hundreds of possible contact arrangements. The technician will have to find his way through whichever arrangement is used in the particular piece of equipment on which he is working. Some typical arrangements are used in the switching circuits covered later in this chapter.

TELEPHONE-TYPE JACKS

The contact assemblies on telephone-type jacks are divided into two categories: (1) the plug contact assembly and (2) the pileup contact assembly. The plug contact assembly includes the contact springs (and all others making electrical connection with them) that make direct contact with the plug when it is inserted. Both categories are illustrated in figure 9-9A.

Figure 9-9C, illustrates the common varieties of plug contact assemblies used on jacks and indicates the code designation for each.

The proper contact arrangement for jacks is determined with the aid of figure 9-9B. The plug contact assembly (J7) is distinguished from the pileup contact assembly (B), and the code designation for the plug contact assembly is determined from figure 9-9C. The type and quantity of each basic form used to make up the pileup contact assembly are determined. In the case of Part B of the figure the proper contact arrangement designation for the jack is "J7-1B."

Jacks are used in plug panels, teletype panels, phone units, and in many other applications

SWITCHING SYSTEMS

TRANSMITTING-STATION ANTENNA SWITCHING

An array of switches used for connecting the several transmitters of a shore-station radio facility to the various antenna systems is shown in figure 9-10. This figure is a rear view showing the arrangement of the movable and stationary blades. The arrangement of the switches makes for great flexibility; that is, any transmitter may be connected to any antenna. Electrical and mechanical interlock features incorporated in each switch unit and the method of wiring the array make the operation practically foolproof. Such errors as "hot switching" (the connection of more than one transmitter to the same antenna, and/or the connection of one transmitter to more than one antenna) are avoided.

Each switch (Rotary Switch SA-160/U) is a 2-section, double-pole, double-throw, air-break knife switch having a capacity of 50 kw at frequencies up to 21 mc. Each switch will carry a maximum current of 15 amperes (rms) and will withstand a maximum peak potential of 40 kv, balanced to ground. The nominal characteristic impedance of each section of the switch is 424 ohms. This switch is designed to be operated from one position to another only when the circuits are deenergized.

The primary purpose of this type of rotary switch (when used in an array) is to provide a means of selectively connecting the individual transmitters employed in a radio facility to the various antenna systems available. To accomplish this, a separate rotary switch must be provided for each transmitter-antenna combination to be connected together. That is, for each transmitter used, a separate switch will be required for each antenna system to which that transmitter may have to be connected.

The switches associated with each transmitter are arranged in horizontal rows, and those associated with each antenna system are arranged in vertical columns as indicated in figure 9-11. This relationship of units permits the shortest and simplest interunit wiring arrangement.

The transmission line from a transmitter, or from a preceding switch in a horizontal row,

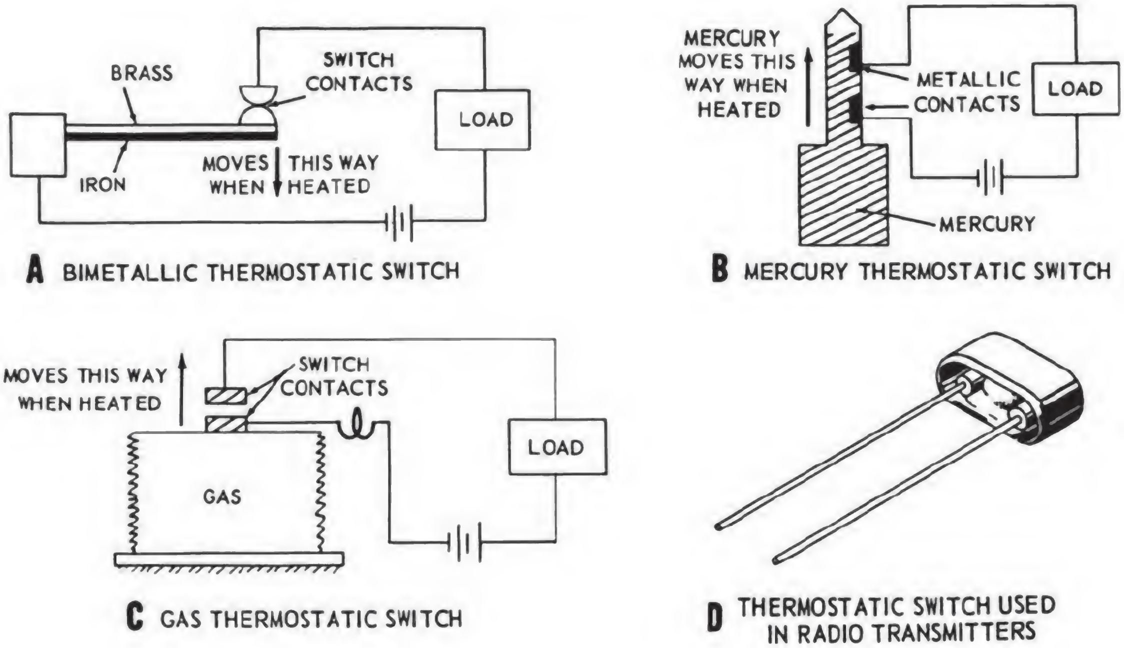

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Figure 9-6.—Thermostatic switches.

connects to the common terminals (upper terminals in the diagram) in the front section of the switch; and the transmission line from an antenna, or from an upper switch in a vertical column, connects to the common terminals in the rear section of the switch. Thus, the front section of each switch performs the function of transmitter switching, and the rear section performs the function of antenna switching. In the switch positions shown in figure 9-10, the three transmitter circuits are not connected to the three antenna circuits.

The switching functions are performed as follows:

1. When a rotary switch (for example, an upper switch in a vertical column) is turned to its ANTENNA ON position (clockwise 90°), the transmission line from the transmitter, or from a preceding switch in the same horizontal row, is connected to the antenna via the common terminals (the upper pair of terminals in each switch) in the front section, the lower right terminals in the rear section, and the common terminals in the rear section. If there is another switch in the equipment above the one being discussed, the circuit continues to the upper switch and then, via the common terminals on the same switch section, to the antenna.

2. When a rotary switch is in its ANTENNA OFF position, the transmission line from the transmitter, or from the preceding switch in the same horizontal row, is connected to other switches that follow in the same row via the common terminals and the lower left terminals, and so on to the last switch, or to a switch that is not in its ANTENNA OFF position.

From figure 9-11 it may be seen that with all switches in the ANTENNA OFF positions, the transmission line from each transmitter will be connected through the first switch in the horizontal row associated with that transmitter to the next switch in the row and through that switch to the next, and so on. Also, the transmission line from the antenna associated with each column to the next lower one, and through that to the next switch, and so on.

When any switch is rotated to its ANTENNA ON position, its two pairs of knife blades swing to their alternate positions and complete a double-pole, double-break circuit from the associated transmitter to the associated antenna. After one switch has been so operated, it will be noted that in connecting the associated

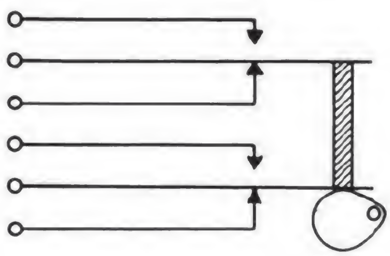

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Figure 9-7.—Rotary pileup switch.

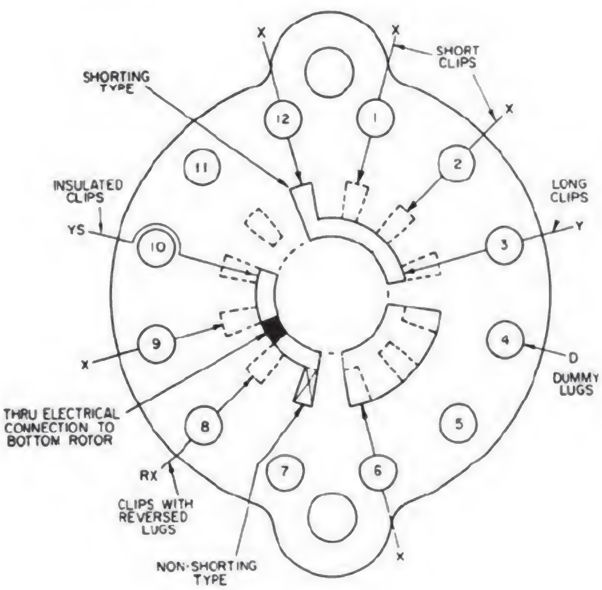

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Figure 9-8.—Deck rotary selector switch, showing contact arrangement and code letters.

antenna to the associated transmitter the following situation is established:

1. The antenna automatically becomes disconnected from the circuit, feeding other switches lower down in the antenna column.

2. The transmission line from the transmitter involved is automatically disconnected from the circuit that feeds the switches further to the left in the transmitter row.

These features alone make it impossible to connect one transmitter to more than one antenna, or more than one transmitter to the same antenna. However, in order to make the system more nearly foolproof, the mechanisms that control the various switches are mechanically and electrically interlocked to prevent more than one switch in any vertical column from being operated at the same time.

The interlock system associated with this switching arrangment is not discussed in this chapter. It is best understood by the use of the instruction book and a visual inspection of the equipment itself.

RECEIVING-ANTENNA DISTRIBUTION SYSTEMS

Most CT M's will be attached to shore stations and will find that the receiving-antenna distribution systems may vary from station to station, depending on the number and types of antennas available and the number and types of multicouplers used. Of course, the same considerations are true of shipboard installations. The following paragraphs will describe shipboard receiving-antenna distribution systems, but the principles of operation will be the same for shore installations. Only the individual equipments, and to some extent, the physical layout, will be different.

Various types of shipboard receiver-antenna distribution systems are in use. Some systems are for small vessels and special applications only. Information about distribution systems is contained in chapter 2 of Shipboard Antenna Details, NavShips 900121; filter-type multicouplers are treated in chapter 11 of this publication.

SYSTEM EMPLOYING TRANSFER PANELS

A receiving-antenna distribution system, using antenna transfer panels, is shown in figure 9-12. The transfer panels are interconnected so that a receiver in any radio space may be connected to any receiving antenna, regardless of its topside location.

Two different views of the antenna transfer panel, Navy type—23406, are shown in figure 9-13 (A and B parts); a simplified schematic diagram is shown in figure 9-13C. These transfer panels provide the means by which as many as four radio receivers may be operated simultaneously from one antenna. At the transfer panel, each antenna is connected to a vertical row of four jacks. One jack is connected directly to the antenna; the other jacks are connected in parallel through 600-ohm

decoupling resistors. Of course, the receivers connected to the three decoupled jacks will operate at reduced efficiency.

There are nine interspace lines (one for each vertical row of four jacks) that connect to the various antennas (fig. 9-13C). These lines connect to the vertical rows composed of four jacks (fig. 9-13A). The escutcheon plate at the top of each line of four jacks is marked to indicate the remote termination of that line.

The 18 intraspace lines (lower 2 rows of jacks) connect to terminal boxes located at the

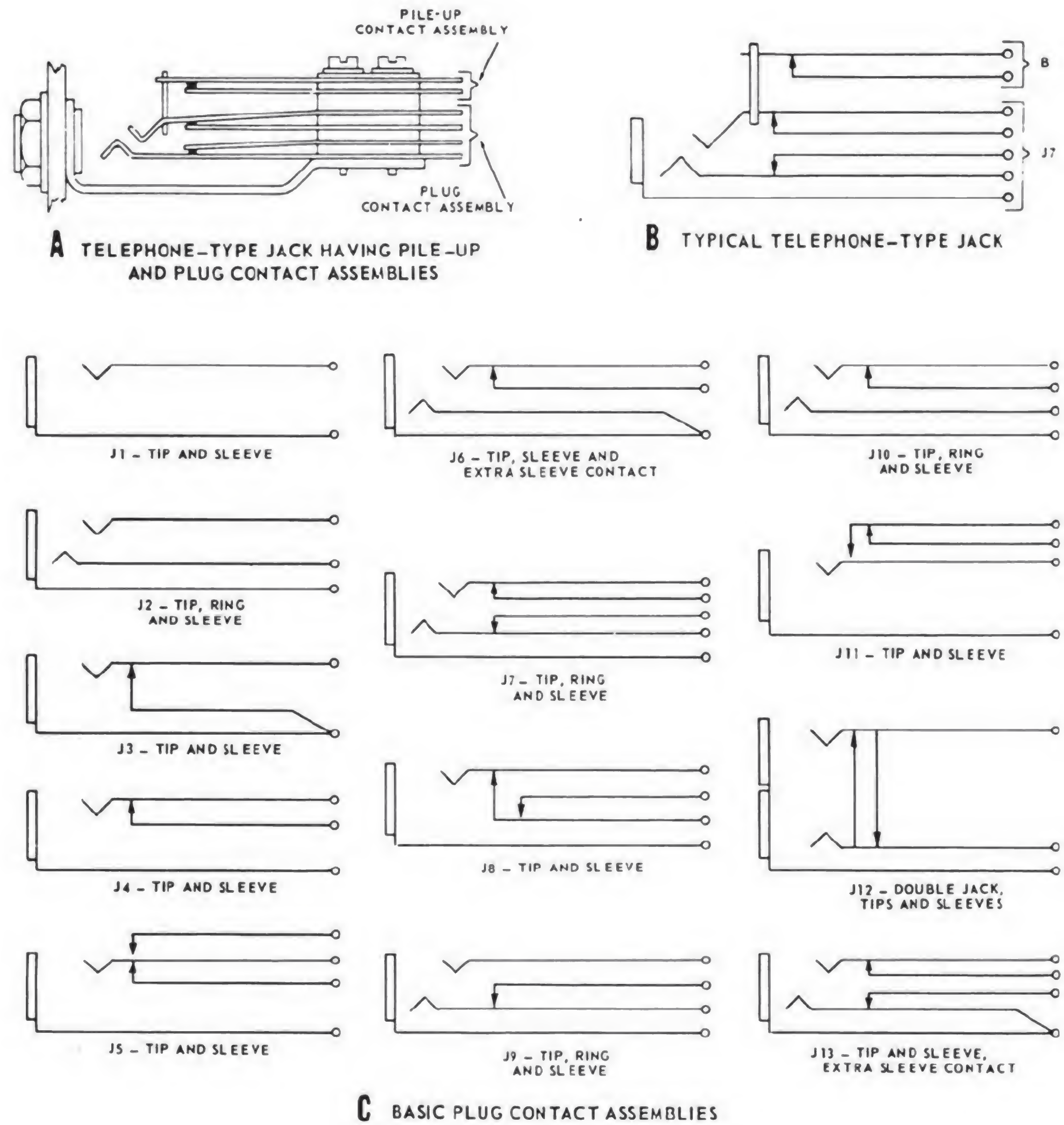

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Figure 9-9.—Telephone-Type Jacks.

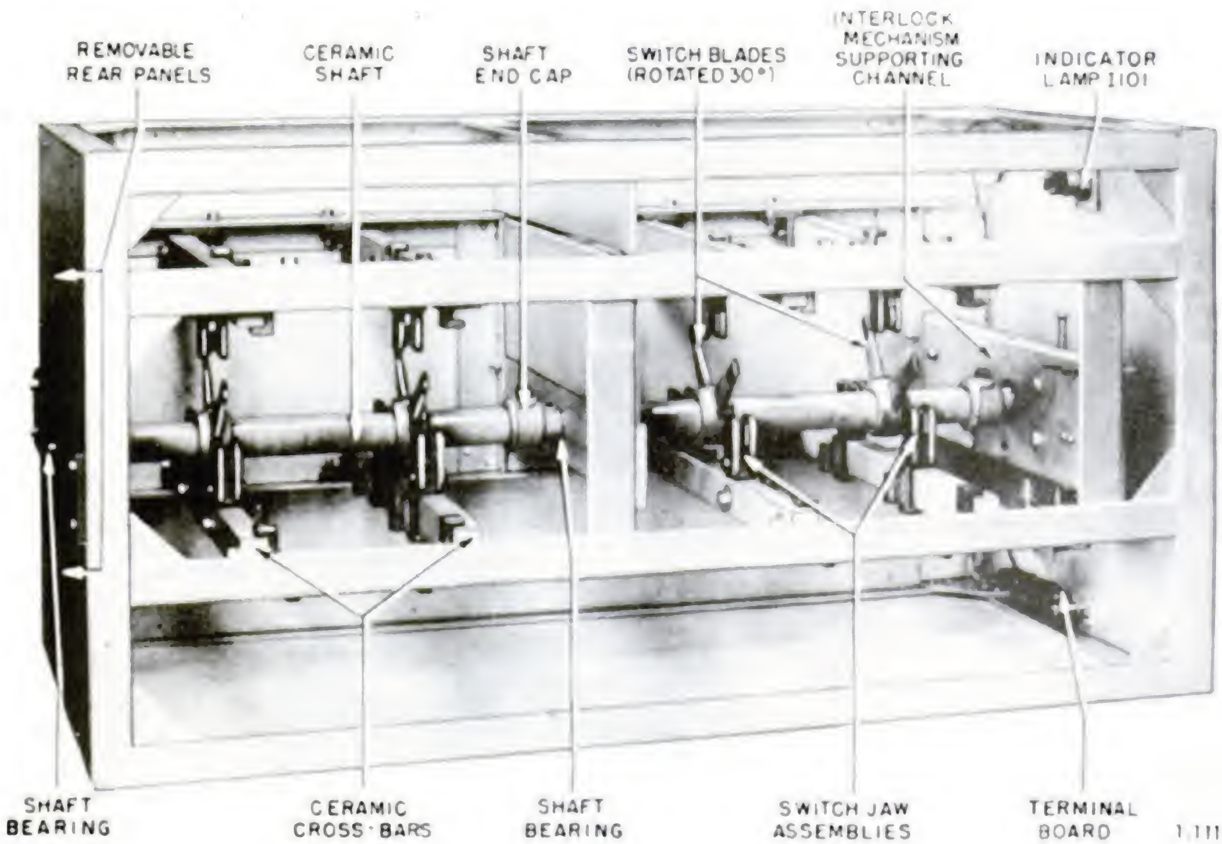

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Figure 9-10.—Transmitter-station antenna switching array, rear view.

various receiver, frequency meter, or other equipment positions. White escutcheon plates are mounted between each pair of jacks to enable the operator to mark the respective communications channel, frequencies, or schedules thereon. Patch cords are provided to complete the connections between the various jacks on the front of the panels.

SYSTEM EMPLOYING FILTER ASSEMBLY

A receiving-antenna distribution system, using a filter assembly, is shown in figure 9-14. This type of distribution system makes possible the multiple operation of a maximum of 28 radio receivers from a single antenna. However, it is generally preferable to limit the total number of receivers to 7.

This filter assembly or "multicoupler" provides 7 r-f channels in the frequency range from 14 kc to 32 mc. Any or all of these channels may be used independently of, or simultaneously with, any of the other channels. Connections to the receivers are made by means of coaxial patch cords and a patch panel.

An external view of the filter assembly is shown in figure 9-14A. Separation of the frequency range into channels is accomplished by combinations of filter subassemblies, which plug into the main chassis. Each filter subassembly consists of complementary high-pass and low-pass filter sections, the common crossover frequency (F_c) of which marks the division between channels.

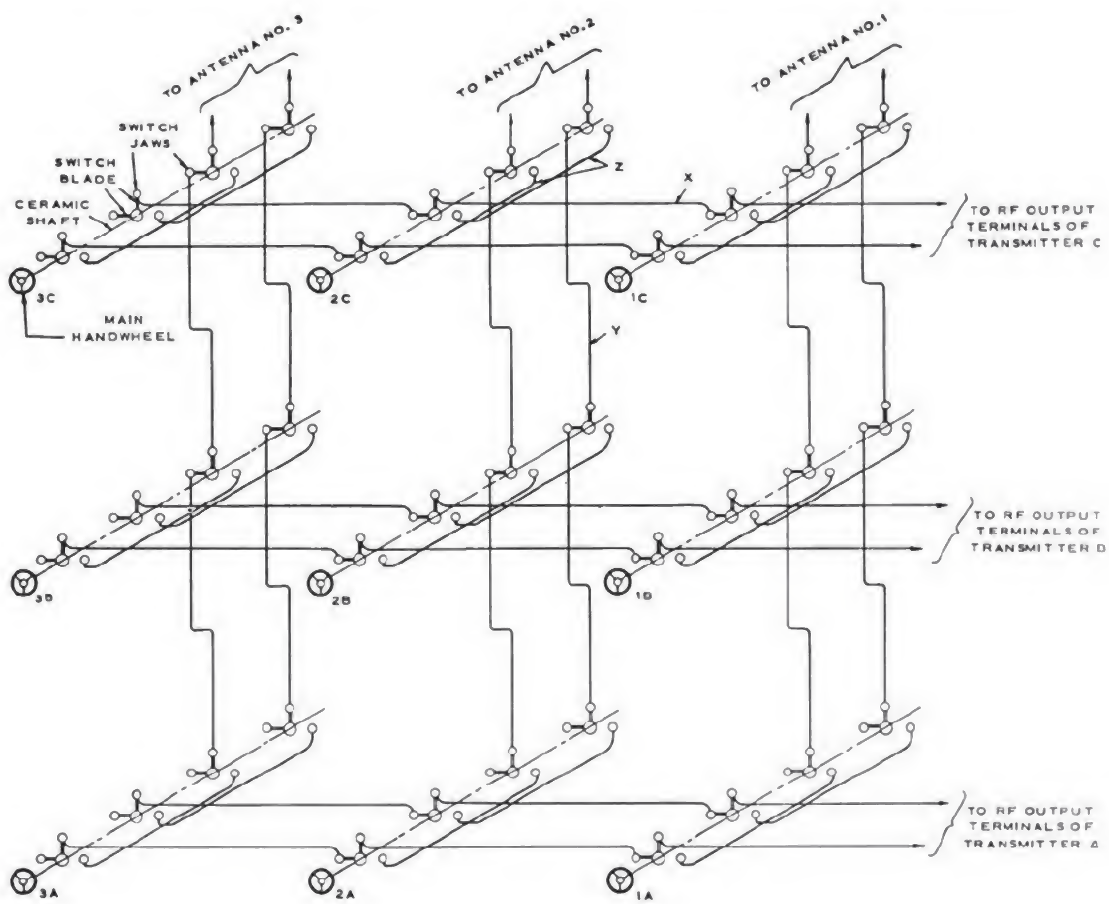
The filters not only guard against interference at frequencies falling outside the channel being used, but also prevent receivers connected to alternate rows of jacks from interacting with each other when their tuning and trimming adjustments are made.

A set of nine filter subassemblies is available, any six of which may be used at one time. The filter subassemblies are sealed units consisting of inductors and capacitors and are terminated in 4-terminal plugs, which are designed to engage octal receptacles on the main chassis. The subassemblies have numbers stamped on them that indicate their crossover frequencies. These numbers can be viewed through windows in the front panel. The six subassemblies that are used are assembled in the order of decreasing frequencies from left to right, as viewed from the front of the panel.

The filter panel (fig. 9-14B) contains 1 antenna input jack, 28 output jacks, 21 decoupling resistors, and 6 octal sockets. The antenna input jack and the 28 output jacks are all Navy type-49120 r-f connectors. In the AN/SRA-12 Receiving Filter Assembly, these connectors have been changed to receptacle connectors UG-1111/U (and plug connectors UG-968/U) which are improved quick-disconnect type r-f connectors. The filter subassemblies plug into octal sockets in the rear of the main chassis (not shown in the figure).

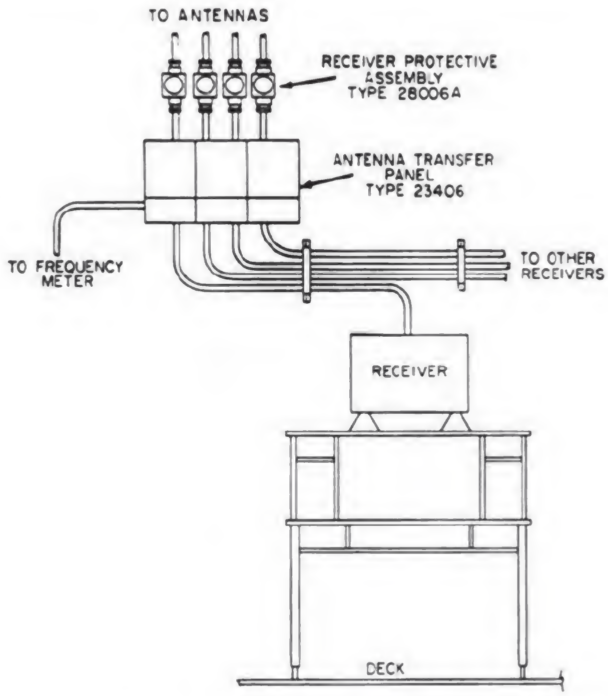
The bottom jack in each vertical row of output jacks is painted red to indicate that it is connected directly to its subassembly. The other three output jacks in each row are unpainted to denote that they are decoupled from their corresponding subassemblies by 300-ohm resistors (fig. 9-14C).

To keep the losses to a minimum, the input and output of the filter assembly should be



1.112

Figure 9-11.—Interconnecting between switch units in an antenna switching array.



1.51.1

Figure 9-12.—Receiving antenna distribution system, using antenna transfer panels.

terminated in 180 ohms. However, only a slight reflection loss (of the order of 1.0 db) results when the input is terminated in 70 ohms, a value typical of the impedance of r-f cables used in receiving-antenna installations aboard ship.

Because Navy communication receivers generally operate throughout frequency bands that exceed the widths of the channels normally provided by the filter subassemblies, a given receiver must be connected to the particular row of output jacks that provides the signals of the desired frequency. For example, if a receiver is tuned from some frequency in the 7- to 14-mc band to some frequency in the 14- to 32-mc band, the patch cord would have to be moved from the output of the 14- to 7-mc subassembly unit to the output of the 32- to 14-mc subassembly unit.

When necessary, the bands of frequencies available in a given row of output jacks may be changed either by using different combinations of filter subassemblies or by removing various subassemblies and inserting "shorting plugs," which are provided with the equipment. These shorting plugs provide continuity between successive subassemblies, as required when testing or when a subassembly is removed for any reason, without the necessity for changing the position of the remaining subassemblies.

The red-painted jacks at the bottom of each row are directly connected to the subassemblies and should be used whenever maximum signal strength is desired. The other 3 jacks in each row are decoupled by 300-ohm resistors and are best suited for use with relatively strong signals. In the ideal arrangement, only one receiver is connected to each vertical row of jacks, and that receiver is connected to the bottom jack in each row. This means that seven receivers are fed from each antenna. At frequencies somewhat removed from the crossover points, the performance of each of these seven receivers should be comparable with that obtained if a given one of the receivers were connected directly to an antenna. Likewise, the performance of 21 receivers connected to the "decoupled jacks" should be comparable with the performance of 3 receivers decoupled in like manner, using conventional patch panels with a given antenna.

SYNCHROS AND SERVO SYSTEMS

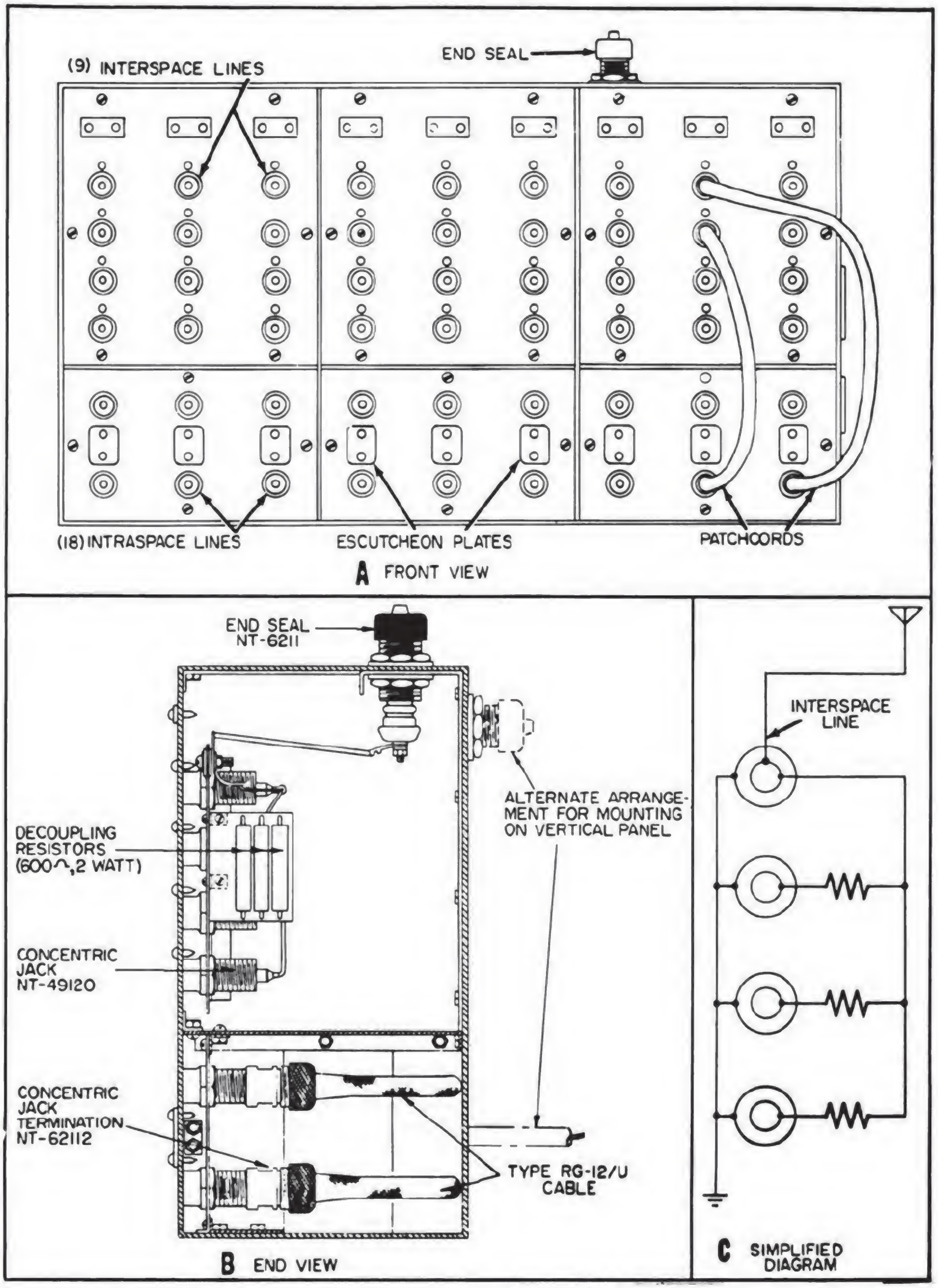
For the guidance of the technician whose assignments include the testing and servicing of synchros, a very brief description of the various types of synchros, and the various functions they perform, is given below.

TRANSMITTER (GENERATOR) SYNCHROS

Transmitter synchros are used to transform an angular position of a shaft to an electrical signal voltage, the voltage being transformed to the identical shaft position by the receiver synchros connected to it. These synchros may be geared or not, depending upon the amount of accuracy required.

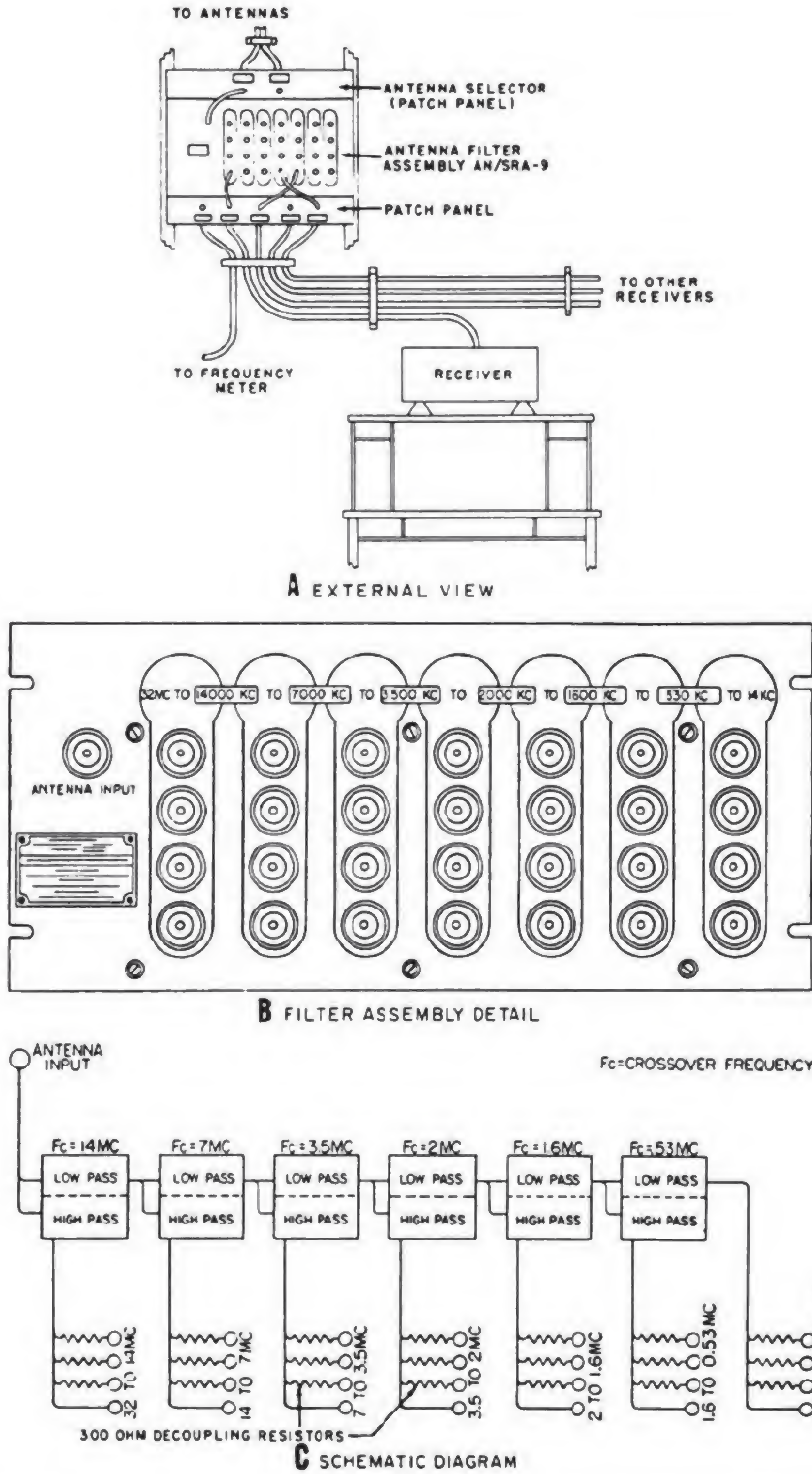
RECEIVER (MOTOR) SYNCHROS

Receiver synchros are used in conjunction with the transmitter synchros. They receive the electrical signal voltage generated by the transmitter synchro and convert it to angular shaft position. These synchros may also be geared or not, depending upon the amount of accuracy required. To prevent overshooting and hunting, the receiver synchro rotor is provided with an



1.114

Figure 9-13. —Antenna transfer panel, Navy type-23406.



1.115

Figure 9-14. —Receiving-antenna distribution system, using antenna filter assembly.

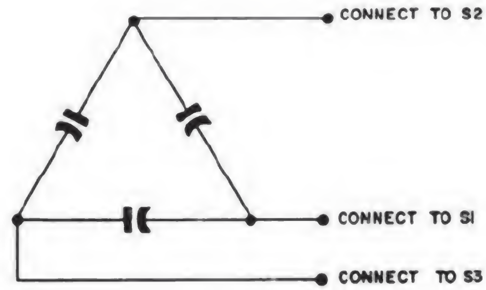
inertia type damping device. For this reason, although a receiver synchro may be used for transmitting, a transmitting synchro may not be used for receiving.

DIFFERENTIAL SYNCHROS

Differential synchros are used in conjunction with transmitter and receiver synchros. When used for transmitting, the differential synchro is used to insert a correction voltage in with the voltage from the transmitter synchro. In effect, the angular position of the transmitter synchro and the angular position of the differential synchro are compared, and the sum or the difference of these two positions is transmitted to a receiver synchro. Whether the sum or the difference voltage of the differential synchro is employed depends upon the method used to connect the transmitter, the differential, and the receiver synchros. A differential synchro which is used as a receiver indicates the angular difference or sum between two transmitter positions.

CONTROL TRANSFORMER SYNCHROS

A synchro control transformer, known as a CT synchro, is similar to an ordinary synchro except that its rotor windings are used for generating a voltage known as an error voltage. Because this voltage is fed to the control grid of an electron-tube amplifier, the rotor windings are wound with many turns of fine wire, to produce a high impedance. Since the rotor is not fed an exciting voltage, the current drawn by the stator windings of the CT synchro would be fairly high if the windings were of the same type as in an ordinary synchro. To prevent this current from being excessive, the stator windings are wound with many turns of fine wire, to present a current-limiting impedance, and, in addition, a capacitor is connected across each of the the three windings. The three synchro capacitors, manufactured in a single package, are shown schematically in figure 9-15.



1.116
Figure 9-15.—Synchro capacitors and connections.

SERVO SYSTEMS

A servo system is a method of control by which a controlled quantity is compared with an ordered quantity, and the difference between the two quantities, known as the error voltage, is used to control the operation of the system. There are a great variety of servo systems in use, and it is not within the scope of this book to describe the systems in detail. There are electronic types, hydraulic types, amplidyne types, and many variations and combinations of these. All of these types of servo systems are designed for a specific task, and the applicable instruction book should be referred to for specific testing and detailed servicing instructions. All of the servo systems have anti-hunt features embodied in their design, in order to prevent oscillation. Electronic amplifiers used in servo systems are classified into the following four basic types:

Type 1. D-c input, d-c output
Type 2. D-c input, a-c output
Type 3. A-c input, a-c output
Type 4. A-c input, d-c output

Block diagrams illustrating these four basic types are shown in figure 9-16. For specialized uses, even these four basic types are varied to suit the particular application for which they may be needed.

SYNCHRO SYSTEM TESTING

Since synchros are employed to transfer angular shaft position to another synchro, usually some distance away, long lengths of connecting bus and/or cable are used. Although the wiring may be clearly marked or color-coded, it is advisable to check these designations if a synchro system gives evidence of improper operation. This is important if a new installation has been repaired or overhauled.

OVERLOAD INDICATORS

An overload in a synchro system is usually caused by worn bearings or defective gears at the receiver synchro. This condition causes the receiver rotor to lag the transmitter rotor, allowing excess current flow in the stator windings. To detect this condition, it is necessary to measure the current in at least two of the stator leads. This is necessary because synchro design makes it possible for one stator lead to indicate zero volts while the other two leads are drawing excessive current. The usual procedures and precautions should be followed when making these measurements. Some synchro systems may have an overload indicator included in the installation. This method utilizes two current transformers, the primary of each being connected in series with a stator lead. The secondary windings of these two transformers are connected in series-aiding, and the two remaining secondary leads are connected to a neon bulb. The secondary windings of these two transformers are so designed that the neon bulb fires when a predetermined unbalance in voltage in the two stator leads is present. The neon bulbs are usually mounted on the control switchboard of the equipment.

BLOWN-FUSE INDICATORS

Some synchro systems may have a blown-fuse indicator included in the installation. This usually consists of a transformer with two primary windings and one secondary winding. The primary power is connected to one primary winding, and the synchro excitation voltage is taken from the other primary winding. The leads of one primary are jumpered by fuses to the leads of the other primary, the phasing being such that the voltages in the two windings oppose one another so that normally no voltage is induced in the secondary. If one of the fuses blows, the primary winding connected to the primary power induces voltage in the secondary winding. This secondary winding is connected to a neon bulb, which glows, indicating a blown fuse.

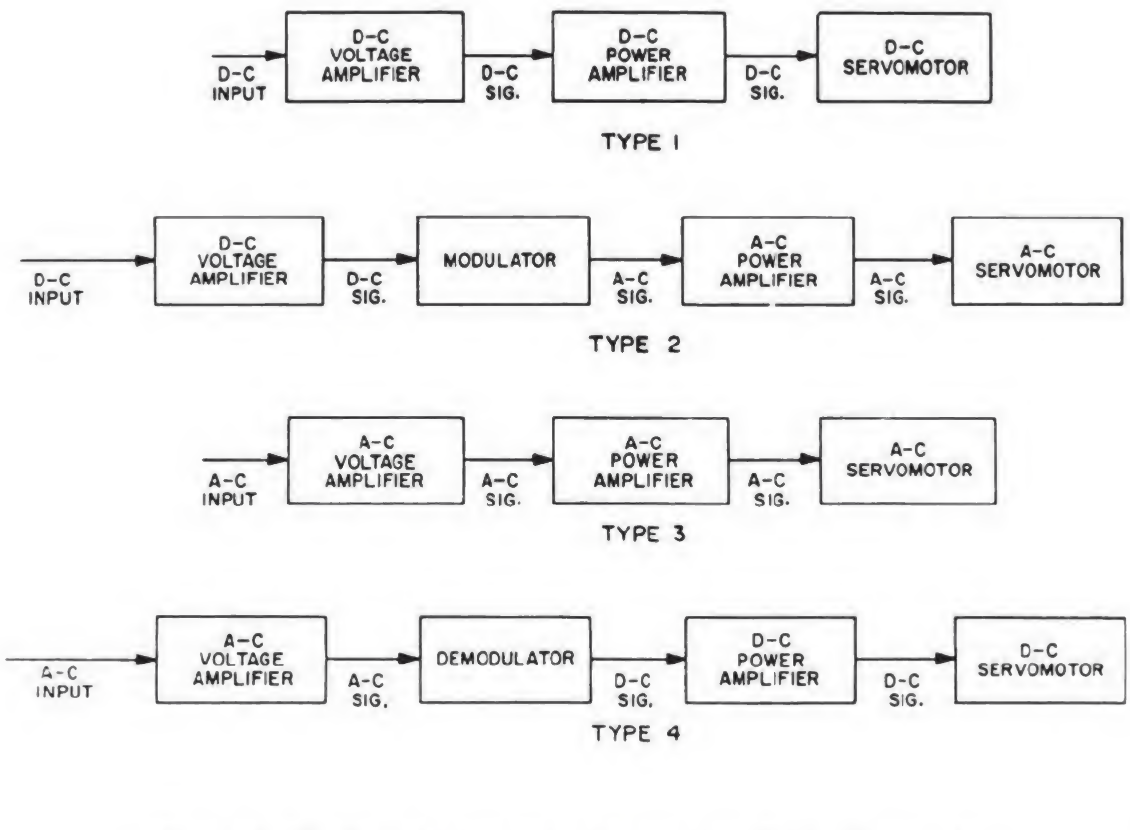


Figure 9-16.—Four basic types of servo amplifiers (electronic).

VOLTAGE AND RESISTANCE MEASUREMENTS

The quickest method of locating opens and shorts in synchro units and their associated wiring is by resistance measurements. Since most synchros work in pairs, it can be assumed that the resistances of both the rotors and the stators will show the same reading, within close tolerances. If the resistances should vary widely, the trouble may be easily located. Typical resistance values for synchros may run from a fraction of an ohm for the large synchros to a few hundred ohms for the smaller ones. Do not measure resistance without first shutting off all excitation voltage to the synchro rotors.

An excellent method for detecting open or shorted stator windings is to connect a voltmeter across any two of the stator windings. As the transmitted quantity is varied, a smooth variation between 0 and 90 degrees should be indicated by the voltmeter. Open or short-circuited stator or rotor leads may be detected by measuring the resistance of the suspected part.

SYMPTOMS AND CAUSES OF INCORRECT WIRING

In new installations and after repairs or overhauls in synchro systems, crossing of buses or wires is frequently the cause of improper synchro operation. Reference to figure 9-17 should identify the cause of any improper operation of the synchro system.

SYNCHRO ZEROING METHODS

In any synchro system it is most important to have all the synchros electrically zeroed. Since different types of synchros must be zeroed in a different manner, each type of synchro will be discussed.

Zeroing Receiver Synchros

Since the receiver synchro is usually free to turn, the jumper method of zeroing is usually employed. To zero a receiver synchro, the voltage between S1 and S3 must be made zero, and the phase of the voltage at S2 should be the same as the phase at R1. This is easily done by connecting S1 and S3, using a jumper wire, and connecting S2 and R1, using a jumper wire. This method is shown in figure 9-18. When the power is applied, the rotor will line up in the zero position. If the indicator does not point to zero on the dial, loosen the synchro in its mounting and rotate it until its dial reads zero.

Zeroing Transmitter Synchros

To zero a transmitter synchro, connect an a-c voltmeter between S1 and S3 as shown in part A of figure 9-19. Rotate the energized rotor until a zero reading is obtained on the voltmeter. Since rotor positions at zero degrees and 180 degrees will produce this zero reading, it will be necessary to determine whether the phase of S2 is the same as that of R1. Make the connections shown in part B of figure 9-19. If the proper polarity relationships exist, the voltmeter will indicate less than the line voltage being applied to the rotor. If the indication is greater than the line voltage, the rotor must be rotated 180 degrees and the previous step, as shown in part A of figure 9-19, performed again. The pointer connected to the rotor should be adjusted to indicate zero.

Zeroing Differential Transmitter Synchros

Because the differential transmitter synchro is usually used to insert a correction voltage into a synchro system, it is normally driven either directly or through a gear train. Before zeroing the differential transmitter synchro, the unit whose position the differential synchro transmits should first be zeroed. After this has been done, connect the differential synchro as shown in part A of figure 9-20. Turn the synchro in its mounting until the voltmeter shows a minimum indication. After completing this step, make the connections shown in part B of figure 9-20. Again turn the synchro slightly in its mounting, until a minimum voltage is indicated by the voltmeter.

Zeroing Differential Receiver Synchros

To zero a differential receiver synchro, make the connections shown in figure 9-21. As soon as the power is applied to the synchro, the rotor will assume a position of electrical zero. The dial can then be set at zero and the unit reconnected to its circuit.

Zeroing Control Transformer Synchros

To zero a control transformer synchro, connect it as shown in part A of figure 9-22.

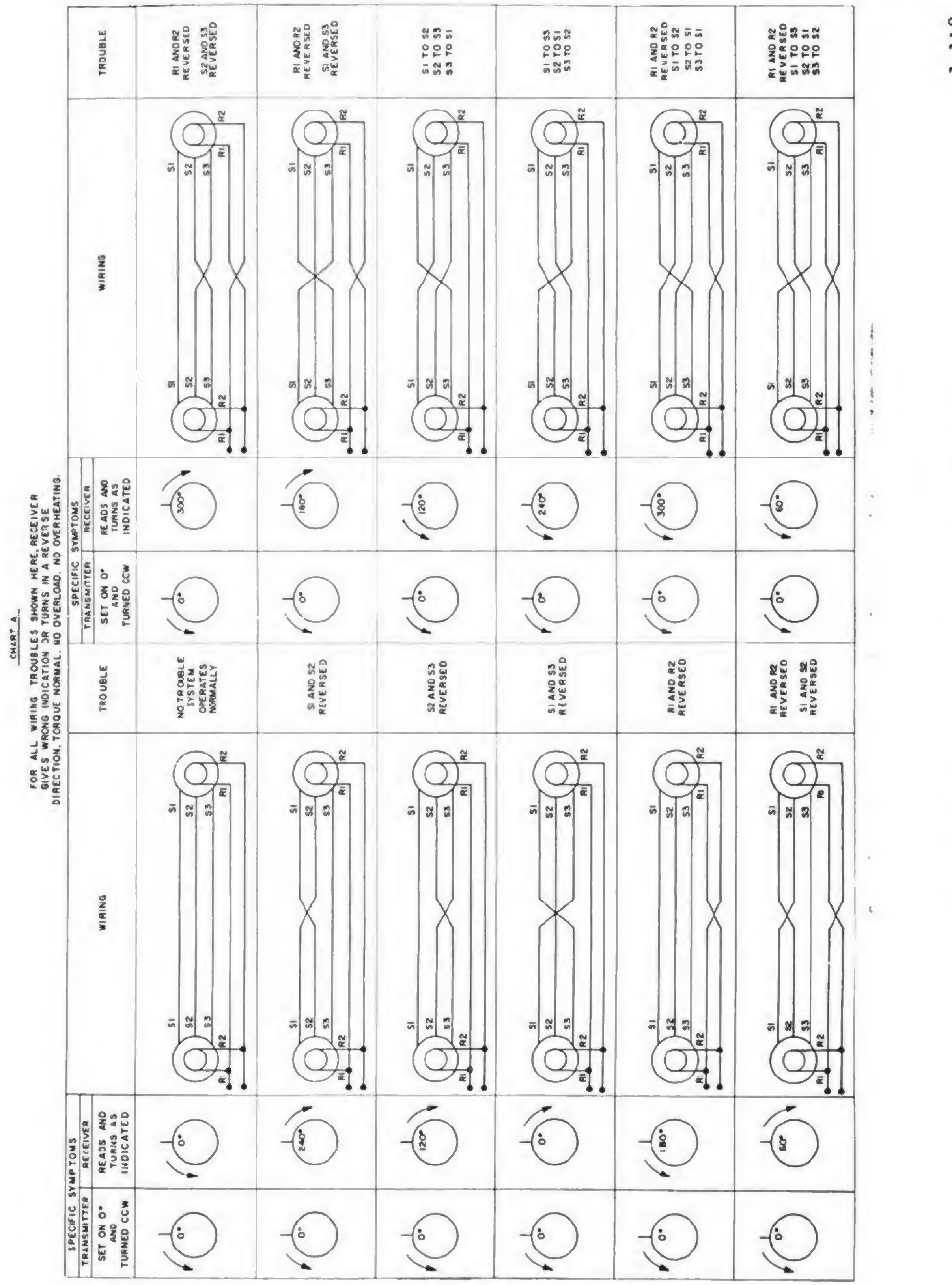
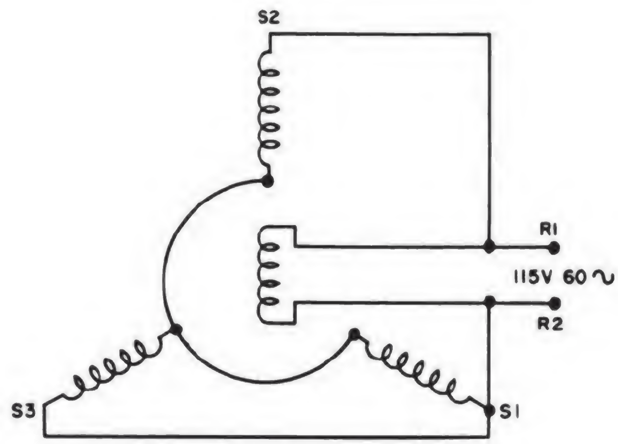


Figure 9-17. —Symptoms and causes of incorrect wiring.

Apply the power and turn the synchro in its mounting for minimum reading on the voltmeter. Connect the control transformer synchro as shown in part B of figure 9-22, and again turn the synchro slightly in its mounting, in either direction, for a minimum indication on the voltmeter.

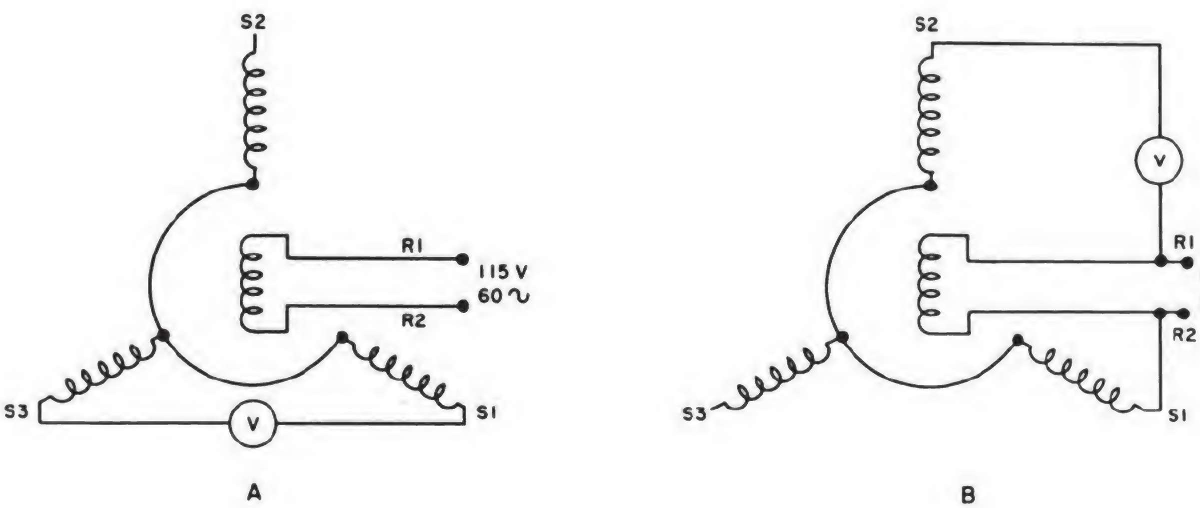
Standard Test Synchros

A standard test synchro is used for performing various operational tests on synchro systems, and may be used for various kinds of checks and for trouble shooting. The standard test synchro is a small, precision synchro, mounted in an instrument case. It is equipped with a standard dial (numbers increasing in a clockwise direction) which moves past an engraved index. When the synchro is being used as a transmitter, a braking arrangement supplies friction to the shaft. When the synchro is being used for receiving, the brake is released to allow the shaft to turn freely.



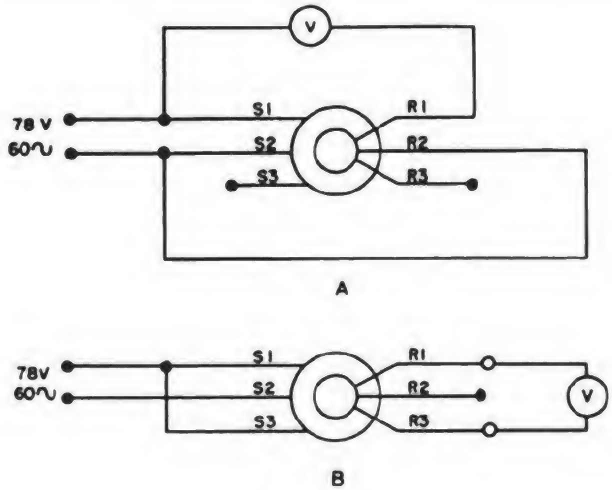
1.119

Figure 9-18.—Method used for electrically zeroing a transmitter synchro.

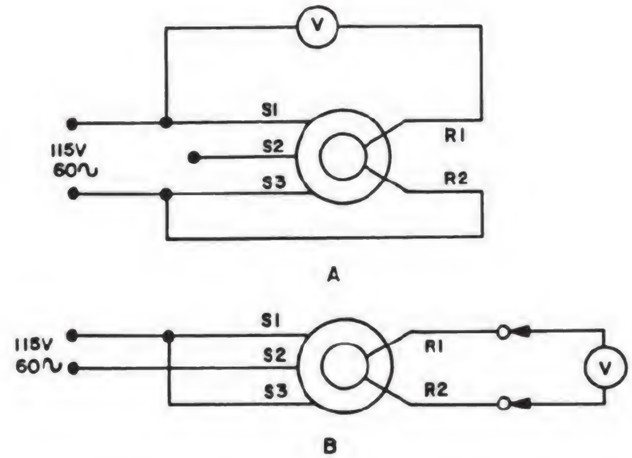


1.120

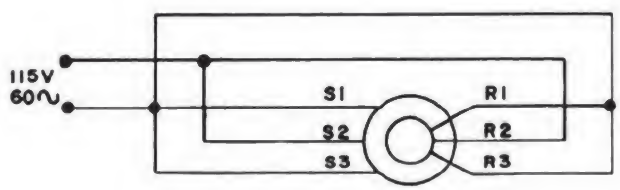
Figure 9-19.—Method used for electrically zeroing a transmitter synchro.



1.121
Figure 9-20. —Method used for electrically zeroing a differential synchro (transmitter).



1.123
Figure 9-22. —Method used for electrically zeroing a control transformer synchro.



1.122
Figure 9-21. —Method used for electrically zeroing a differential synchro (receiving).

CHAPTER 10

RADIO WAVE PROPAGATION

TERMS AND DEFINITIONS

In this discussion of radio wave propagation, a number of technical terms are used. to help you understand the material, the following list of terms and definitions is provided:

ANTENNA. A device used to radiate or receive radio waves.

ATMOSPHERE. The whole mass of air surrounding the earth, including the troposphere, stratosphere, and the ionosphere.

ATTENUATION. The decrease in signal strength of a radio wave with distance in the direction of propagation.

CONDUCTIVITY. A measure of the ability of a material to act as a path for electon flow. It is the opposite of resistivity and is expressed in mhos per meter.

CRITICAL FREQUENCY. The limiting frequency below which an electromagnetic wave is refracted back to earth by, and above which it penetrates through, an ionospheric layer at vertical incidence (straight up).

DECIBEL (DB). A term meaning one-tenth of a bel. The ratio of a change in power after attenuation or amplification.

DIFFRACTION. The bending of a radio wave into the region behind an obstacle.

DIRECT WAVE. A radio wave that is propagated directly through space from transmitter to receiving antenna.

DISTORTION. An undesired change in waveform.

FADING. The variation of radio signal strength at a radio receiver during the time of reception.

FREQUENCY OF OPTIMUM TRAFFIC (FOT). The most reliable frequency at a specified time for ionospheric propagation of a radio wave between two specified points.

GIGACYLE (gc). An expression denoting 10^9 cycles per second (1000 mc).

GROUND WAVE. A radio wave that travels close to the earth and reaches the receiving point without being refracted or acted upon by the ionosphere. The ground wave includes all components of a radio wave traveling over the earth except the sky (ionospheric) wave.

INCIDENT WAVE. A term denoting that portion of a radio wave which is about to strike a medium of different propagation characteristics which will result in that wave being refracted, reflected, diffracted, or scattered.

IONOSPHERE. The part of the earth's outer atmosphere where ions and electrons are present in quantities sufficient to affect the propagation of radio waves. The portion of the atmosphere above the stratosphere.

ISOTROPIC ANTENNA (UNIPOLE). A hypothetical antenna equally radiating or receiving energy in all directions.

LOWEST USABLE FREQUENCY (LUF). The LUF, based on the signal-to-noise ratio, varies as the power or the bandwidth is varied. An increase in power or a decrease in bandwidth will lower the LUF, and a decrease in power or increase in bandwidth will raise the LUF. A small change in power will not materially effect the LUF.

MAXIMUM USABLE FREQUENCY (MUF). The upper limit of the frequencies which can be used at a specified time for radio transmission between two points involving propagation by refraction from the regular ionized layers of the ionosphere. (Frequencies higher than the MUF may be transmitted by sporadic and scattered reflections.)

NOISE. Any extraneous electrical disturbance tending to interfere with the normal reception of a transmitted signal.

REFLECTION. The phenomenon which, when a radio wave strikes a medium of different propagation characteristics (such as the earth or ionosphere), causes the wave to be

returned into the original medium (ionosphere or the earth) with the angles of incidence and of reflection equal and lying in the same plane.

REFRACTION. The phenomenon which, when a radio wave or other radiation passes from one medium (such as the stratosphere) to another medium (such as the ionosphere), causes the wave to bend. The angles of incidence and of reflection are not equal or necessarily lying in the same plane.

SKY WAVE. A radio wave that is propagated or acted upon by the ionosphere.

SPACE WAVE. Often called the tropospheric wave. A radio wave that travels entirely through the earth's troposphere.

STRATOSPHERE. The part of the earth's atmosphere between the troposphere and the ionosphere.

SUNSPOT NUMBERS. The number of dark irregularly shaped areas on the surface of the sun caused by violent solar eruptions. The spots are counted and then averaged over a period of time to obtain values which are expressed as "smooth sunspot numbers." These smooth sunspot numbers are used to predict the average sunspot activity over a period of time.

SURFACE WAVE A radio wave that travels in contact with the surface of the earth.

TROPOSPHERE. The lowest part of the earth's atmosphere. In this region, which extends from the surface of the earth to the stratosphere, temperature decreases with altitude, clouds form, and all weather phenomena take place.

GENERAL CHARACTERISTICS OF RADIO WAVES

Radio waves are a form of electromagnetic radiation similar to light and heat waves. They differ from the other radiations in the manner in which they are generated and detected, and in their frequency range which is from approximately 3 kc to 300 gc. The radio frequency spectrum is divided into various bands of frequencies as shown in the following table.

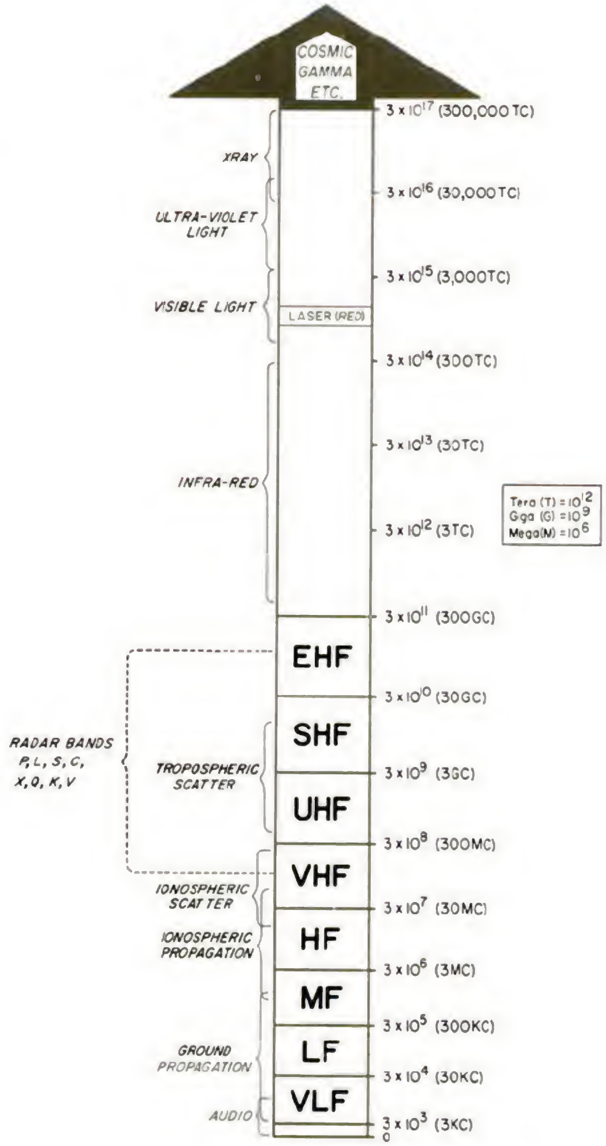
Figure 10-1 shows the entire energy spectrum of which the radio spectrum is only a small part. Radio waves travel at the same velocity as light waves, which in free space have a speed of approximately 186,000 miles per second or 300,000,000 meters per second. The wavelength of a radio signal is the distance that the wave travels in one cycle, during which its electromagnetic or electrostatic displacements have a difference in phase of one complete period. Wavelength is also described as the distance from the crest of one wave to the crest of the next. The wavelength of any radio wave can be found by the formula: $\lambda = \frac{c}{f}$ where λ is the wavelength, f the frequency in cycles, and c the constant velocity of light.

Table 10-1. —Radio Frequency Spectrum.

FREQUENCY	DESCRIPTION	ABBREVIATION
30gc-300gc	extremely high frequency	EHF
3gc-30gc	super high frequency	SHF
300mc-3gc	ultra high frequency	UHF
30mc-300mc	very high frequency	VHF
3mc-30mc	high frequency	HF
300kc-3mc	medium frequency	MF
30kc-300kc	low frequency	LF
3kc-30kc	very low frequency	VLF

WAVE POLARIZATION

A radio wave consists of traveling electric and magnetic fields. The lines of force of these fields are perpendicular to each other and at right angles in a plane which is perpendicular to the direction of travel. The polarization of the radio wave is determined by the direction of the electric field of the wave with respect to earth. If the electric field is vertical (perpendicular) to the earth (figure 10-2), the wave is said to be vertically polarized. If the electric field is horizontal (parallel) to the earth, the wave is said to be horizontally polarized. Vertically positioned transmitting antennas radiate vertically polarized radio waves. Horizontal transmitting antennas radiate horizontally polarized radio waves.



93.11

Figure 10-1.—Energy Spectrum.

REFLECTION, REFRACTION, AND DIFFRACTION OF RADIO WAVES

Reflection

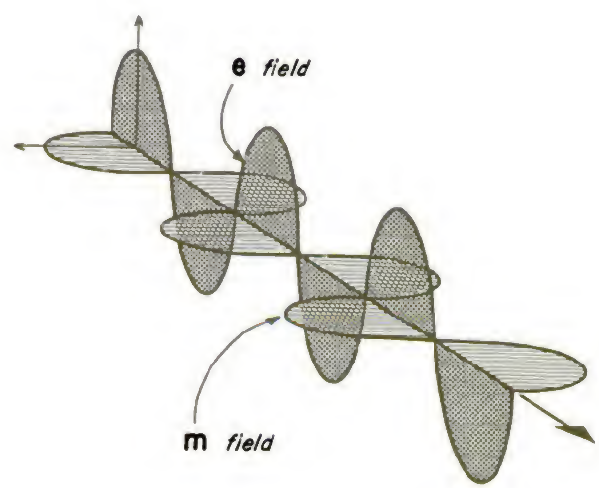
Radio waves can be reflected, refracted, and diffracted in a manner similar to light and heat waves. They may be reflected from any sharply defined substances or objects of suitable characteristics and dimensions which are encountered in the medium of travel. The wave is not reflected from a single point on the reflector but rather from an area of its surface. The size of the area required for reflection depends on the wavelength and angle of incidence. When a wave is reflected from a plane (flat) surface, a phase shift occurs, as shown in figure 10-3. The amount of phase shift depends on the polarization of the wave and the angle of incidence.

Refraction

As in the case of light, a radio wave is bent when it moves from one medium into another in which the velocity of propagation is different from that of the first medium. The bending, which is called refraction, is always toward that medium in which the velocity is the least. If a wavefront is traveling obliquely from the earth and encounters a medium with a greater velocity of propagation, the part of the wavefront that first enters the new medium travels faster than parts of the wavefront which enter later. The difference in the rate of travel tends to swing the wavefront around or to refract it in such a manner that it is directed back to earth.

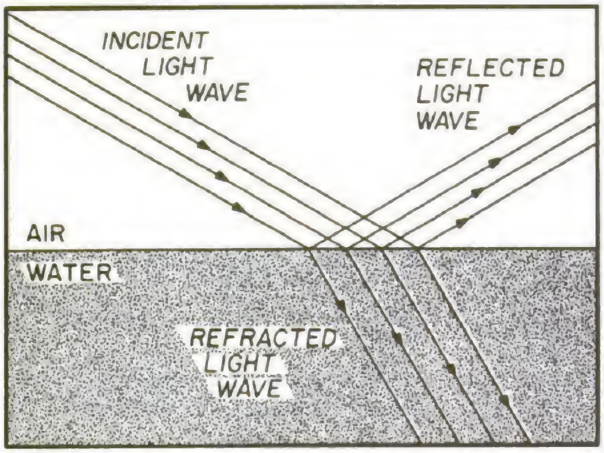
Diffraction

A radio wave is also bent when it passes the edge of an object. The bending, called diffraction,



93.12

Figure 10-2.—Instantaneous cross section of a radio wave-front.



93.13

Figure 10-3.—Reflection and refraction of a light beam.

results in a change of direction of part of the energy from the line-of-sight path. This change makes it possible to receive energy at some distance below the summit of an obstruction or around its edges. A later section will show how, in the field of ground wave propagation, radio waves are diffracted beyond the earth's horizon. In certain cases, by using high power and very low frequencies, the waves can be made to encircle the earth by diffraction.

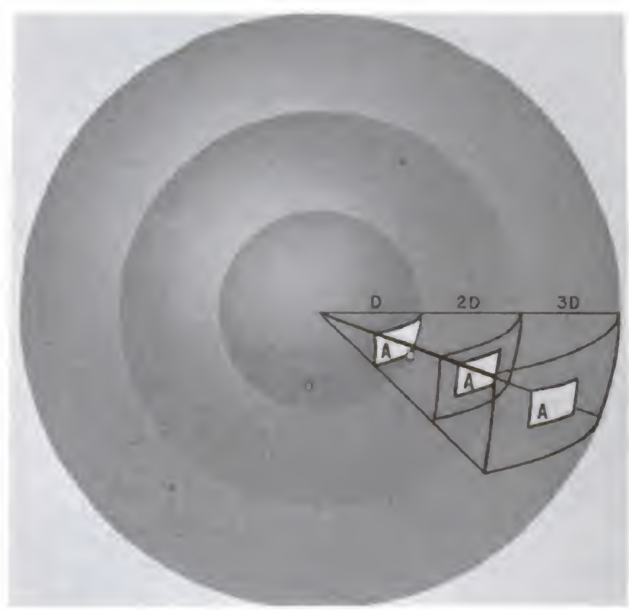
TYPES OF RADIO WAVES

The wave which is transmitted from an antenna can be considered to have two major components. One major component is the ground wave, which consists of two parts. One part travels along the ground and follows the curvature of the earth. This is the surface wave. The second part is the space wave, which is that part of the total radiation that undergoes refraction, reflection, or scattering from regions in the troposphere. The second major component is the sky (ionospheric) wave, which is radiated in an upward direction and returned to the earth at some distant location due to refraction or scattering from the ionosphere.

All types of waves are affected by the condition of the earth's surface or by one or more regions of the constantly changing atmosphere. However, for purposes of further discussion and in order to introduce fundamental concepts of propagation in a simple manner, we begin by considering the hypothetical properties of transmission in free space. The hypothetical transmission is between two antennas so isolated in space that no objects exert a measurable influence on the transmission.

TRANSMISSION IN FREE SPACE

There is a certain amount of attenuation or loss of energy even for radio signals transmitted in free space. This loss is due to the spreading of energy over a greater area as the transmission distance is increased. The loss is directly related to the frequency and transmission distance. The intensity of energy is the power per unit of area on the spherical wavefront. The relationship between intensity of energy and distance is illustrated in figure 10-4 which shows the pattern of radiated energy spreading directly with the square of the distance which results in the intensity of radiated energy decreasing inversely with the square of the distance from the isotropic antenna in free space. An isotropic antenna uniformly radiates energy in



93.14

Figure 10-4.—Free-space pattern of an isotropic antenna showing change in intensity of radiated energy with distance.

all directions or receives energy equally well from all directions.

Figure 10-4 illustrates the fact that free-space loss introduces a substantial attenuation in the transmitted signal. This is the basic loss which occurs for all types of radio transmissions. For line-of-sight circuits, where the conditions for free-space propagation are closely approximated, the total loss can be considered to be the free-space loss. However, for long distance communications, where either ground-wave, sky-wave, or scatter propagation is used, other losses are introduced by the effects of the earth and the atmosphere. Each of these losses must be added to the free-space loss to find the total attenuation of the transmitted signal.

THE SUN

The controlling body of our solar system, the sun, is a star whose dimensions cause it to be classified among stars as average in size, temperature, and brightness. Its proximity to the earth makes it appear to us as tremendously large and bright. A series of continuous atomic reactions, involving the elements of which the sun is composed, produces the heat and light waves that are received through the earth's atmosphere.

DIMENSIONS. The sun has a diameter of 864,000 miles and its average distance from the earth is 92 million miles.

DENSITY. The sun has a density of 1.41 times that of water.

DISTANCE IN TIME. Light waves from the surface of the sun reach the earth in slightly more than 8 minutes.

TEMPERATURE. The average solar temperature has been measured by several indirect methods which agree closely on a value of 6000 degrees centigrade or about 10,000 degrees Fahrenheit; however, the interior temperature of the sun is about 35,000,000 degrees Fahrenheit. The radiating surface of the sun is called the photosphere (see figure 10-5). Just above that surface is the chromosphere which is a layer of solar atmosphere in a constant state of agitation as if stirred by spouting gasses. The chromosphere is visible to the naked eye only at times of total solar eclipses, appearing then to be a pinkish-violet layer with great, swiftly moving spoutings. These spoutings, which project above the chromosphere's average level, are called prominences. With proper instruments the chromosphere can be seen or photographed whenever the sun is visible. Above the chromosphere is the corona, a bluish-violet light also visible to the naked eye only at times of total eclipse. The brighter parts of the corona can be studied with instruments whenever conditions are favorable. The corona surges millions of miles into space and is believed to be composed of atomic particles of iron, nickel, and calcium.

SUNSPOTS

Sunspots are dark irregularly shaped areas on the surface of the sun. Their diameter may reach several hundreds of thousands of miles. There is a direct relationship between sunspots and the corona. During low sunspot activity, the corona streamers will be much longer above the sun's equator than over its polar regions; during high sunspot activity, the corona streamers extend out evenly over the entire surface of the sun but to a much greater distance span. It is believed that these sunspots and the associated high corona streamers are responsible for the cyclic variations in the ionization level of the ionosphere.

SHORT WAVE FADEOUT

Quite frequently violent sunspot activity produces effects in the earth's ionosphere called Short Wave Fadeout (SWF), formerly know as Sudden Ionospheric Disturbances. During a SWF "squirts" of abnormally strong ultraviolet radiation cause the level of ionization in the lower part of the ionosphere to rise sharply. In these situations radio signals—especially those in the HF band—may be absorbed or refracted back to earth short of the intended receiving site. During SWF, the lower frequencies are absorbed first and recovered last. During SWF of low intensity, transmission may continue to be possible on the higher frequencies. SWF normally occurs only in the daylight hemisphere and is characterized by simultaneous fadeouts on a wide range of the useful high frequency band.

IONOSPHERIC PROPAGATION

A basic understanding of the ionosphere—what it is and how it is formed—is necessary in order to understand how it affects radio

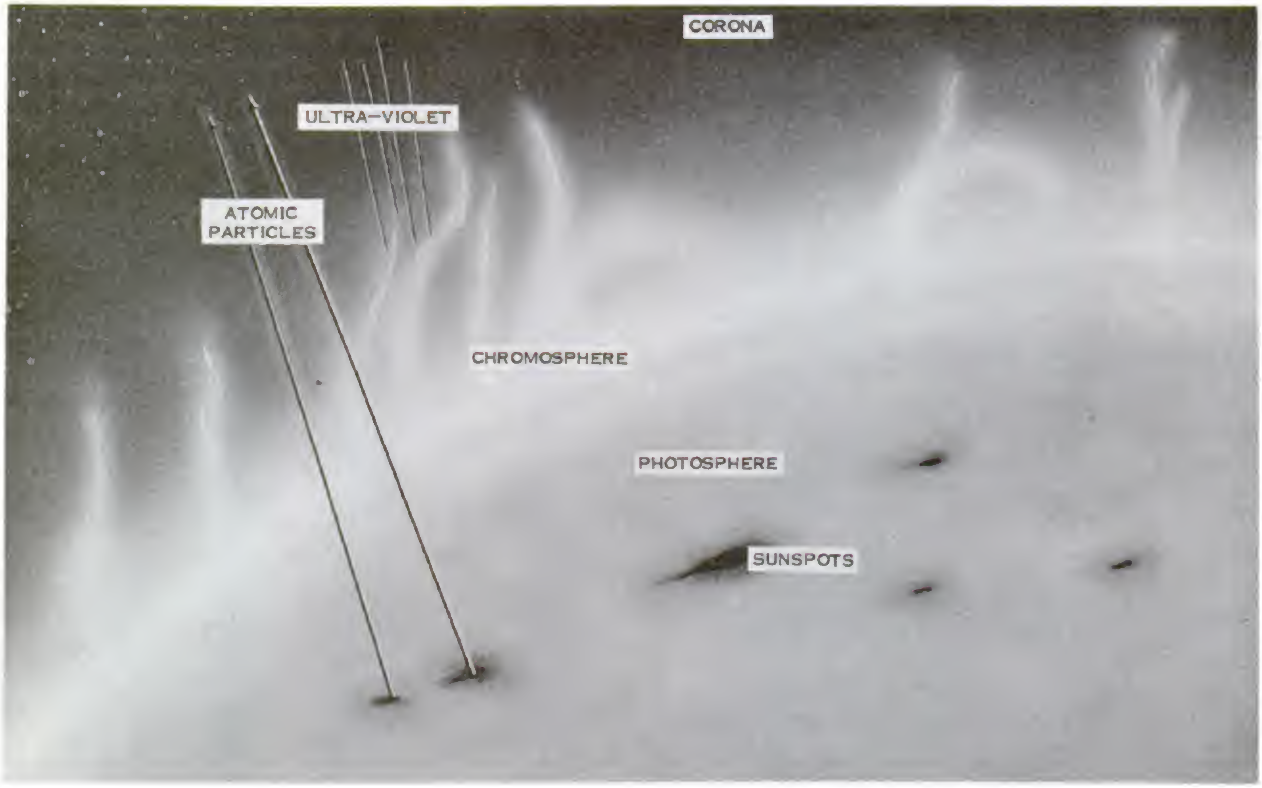


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Figure 10-5.—Composition of the sun.

wave propagation. The following paragraphs provide a description of the ionosphere.

STRUCTURE OF THE IONOSPHERE

The ionosphere is the area of the atmosphere in which the gas atoms are charged by ultraviolet light from the sun and by meteor activity. These charged atoms are called ions; the process by which they are charged is called ionization.

Ionization occurs as follows. When a high-energy electromagnetic wave, such as ultraviolet light, hits an atom, it is capable of knocking an electron free of its parent atom. When this occurs, a positively charged atom, called a positive ion, remains in space along with the negatively charged free electron. The electron absorbs energy from the incident wave which frees it from its parent atom. The rate of ion and free electron formation depends upon the density of the atmosphere and the intensity of the ultraviolet light. As the ultraviolet light wave produces positive ions and negative free electrons, its intensity is decreased because of the absorption of energy by the free electrons. Therefore, the ionized region will tend to form in a layer for a given frequency of ultraviolet light. When the wave first hits the ionosphere, it has high energy, but the ionosphere is not dense at its highest altitudes; therefore, little ionization will occur. As the wave passes through the ionosphere, the density increases, but the energy level of the wave decreases. An ionized layer forms where the combined effect of ionospheric density and wave energy is maximum.

Since there are different ultraviolet wave frequencies, several ionized layers are formed, as shown in figure 10-6. Lower frequency ultraviolet waves tend to produce ionized layers at higher altitudes. The higher frequency ultraviolet waves tend to penetrate deeper into the ionosphere before producing appreciable ionization.

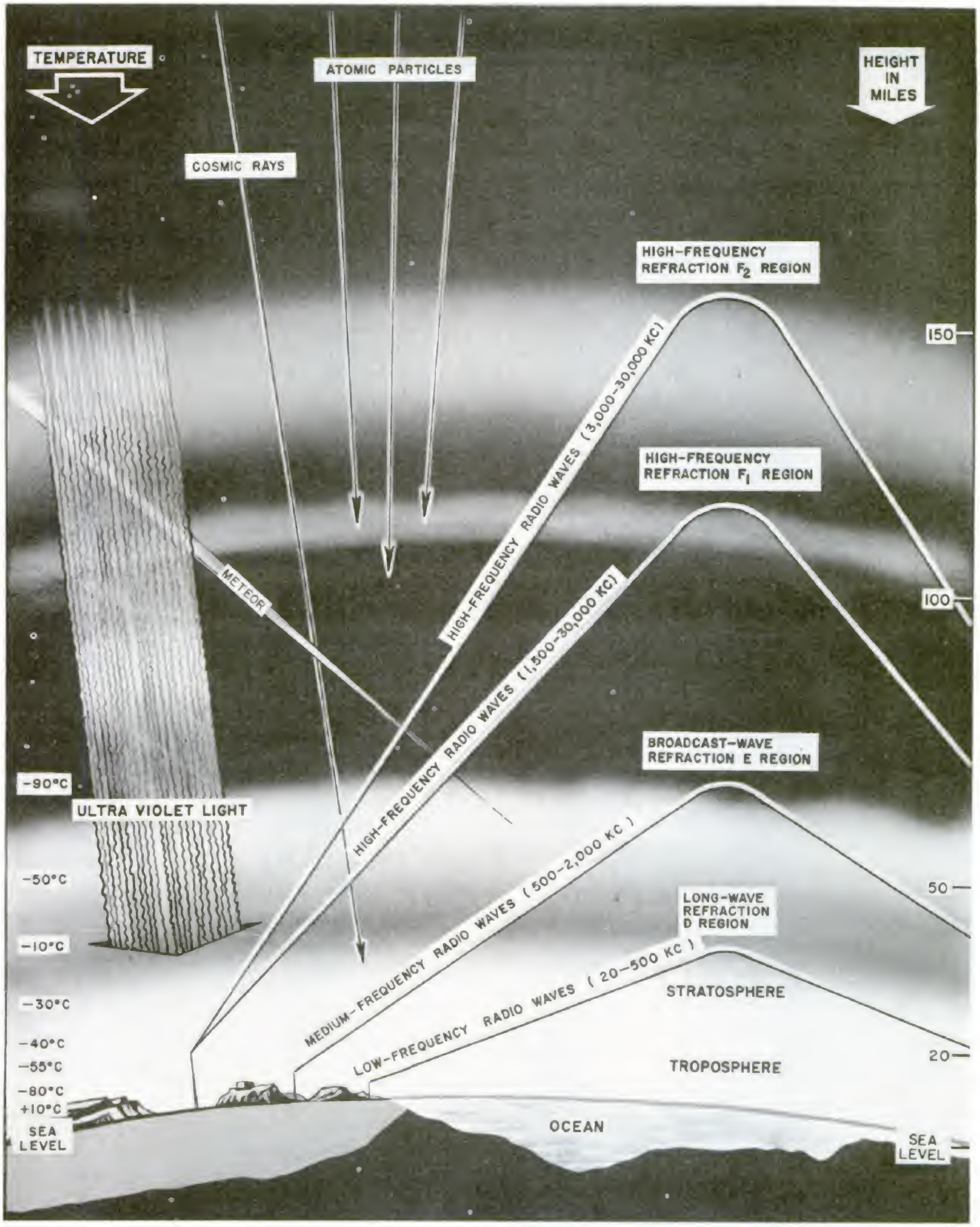

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Figure 10-6.—Composition of the earth's atmosphere.

Ionospheric Layers

Figure 10-6 shows that there are four distinct layers of the ionosphere which are designated D, E, F1, and F2. The height, thickness, and intensity of ionization for each of the layers is measured by transmitting r-f pulses vertically into the ionosphere and then receiving the returned pulse. The echo time indicates the height of the ionospheric layer; the strength of the received signal indicates the thickness of the layer. When pulses of various r-f frequencies are transmitted, a frequency will be found above which the vertical wave will not be refracted back to earth. This frequency, called the critical frequency, indicates the extent of ionization. The higher the critical frequency, the greater the ionization. Since the ionospheric layers are caused chiefly by ultraviolet light emitted from the sun, their height and thickness change with the season and the time of day.

The D layer exists only in the daytime. Very little sky-wave refraction is obtained from this layer, and there is a pronounced absorption effect at frequencies below 2 mc. The E layer exists only during daylight hours at a height of about 55 to 85 miles. The F1 layer exists at a height between 85 and 155 miles during daylight hours. When the sun sets, the F1 layer merges with the next higher ionized layer, the F2 layer. The F2 layer is the most useful layer for sky-wave transmission because it exists during the night as well as the day. This layer occurs between 90 and 150 miles above the earth at night during all seasons. In the northern hemisphere, the F2 layer is somewhat higher in the summer than in the winter during the day, extending between 90 and 180 miles in altitude. The variation in height is accounted for by an increase in ultraviolet radiation which increases the height of the F2 layer and decreases its ion density during the summer. The reduction of ultraviolet radiation in the late afternoon causes the F2 layer to descend.

Besides the seasonal and daily changes in the ionosphere, other variations occur. There is a noted increase in ionization with an increase of sunspot activity. Sunspots produce vast amounts of ultraviolet energy; therefore the greater the number of sunspots, the greater the amount of ionization. Observers of solar activity over the past 100 years have confirmed that sunspot activity is cyclic, with the cycle repeating every 11.1 years. There are variations within this period and variations from one period to the next, all of which make it necessary to know the predicted sunspot number for a given time in order to determine the probability of obtaining efficient sky wave communication.

Sporadic E Layer

Another phenomenon associated with the ionosphere is the sporadic E layer which occurs roughly at the height of the E layer at irregular times and locations, both day and night. The critical frequency of the sporadic E layer may be much higher than that of the regular E layer, and successful refraction from the sporadic E layer may be effective at frequencies up to 60 mc.

REFRACTION IN THE IONOSPHERE

When a radio wave is transmitted into the ionosphere, the wave is refracted. The refraction, or bending, is caused by a change in velocity of the segments of the wavefront as it strikes the ionized layer at an oblique angle. The portion of the wavefront first striking the ionized layer undergoes bending while other portions of the wavefront which have not yet reached the ionized layer are still traveling in a straight line. The amount of bending depends upon the electron density of the ionized layer and the frequency of the transmitted wave. The effect of each of these factors is discussed in the following paragraphs.

Each ionized layer consists of a central region of relatively dense ionization which tapers off in intensity both above and below the maximum region. As a wave passes into a layer of increasing ionization, the velocity of the upper part of the wave increases, causing the wave to bend back toward the earth. If the wave enters into a layer of decreasing ionization, the velocity of the upper part of the wave decreases, and the wave is bent away from the earth. The amount of bending in both cases depends upon both the variation in ionization and the height of the ionized layer. If the wave strikes a thin, very highly ionized layer, the wave will be bent back so rapidly that it will appear to have been "reflected" instead of refracted back to earth. To "reflect" a radio wave, the highly ionized layer must be approximately no thicker than one wavelength of the incident wave. Since the ionized layers often are several miles thick, ionospheric "reflection" is

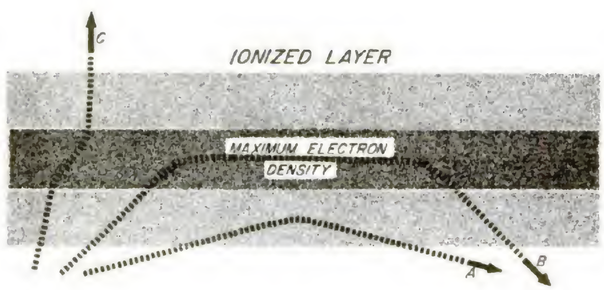

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Figure 10-7.—Change in bending of radio waves in a ionized layer with a change in angle of incidence.

more likely to occur at long wavelengths (low frequencies). The wave is bent (refracted) more slowly (as shown in figure 10-7) when there is a gradual change in the relationship between ionization density and increased height.

The amount of refraction required to return the wave at a given frequency to earth depends on the angle at which the wave enters the ionized region (incident angle). The relationship is shown in figure 10-7 in which the radio waves of the same frequency are beamed toward the ionosphere at various angles. Because wave A approaches the ionized layer at a small angle, only a slight amount of bending is required to return it to earth. Because wave B approaches at a greater angle and penetrates deeper into the ionized layer, a longer path is required for bending it since the variation in density with height is more gradual. Because wave C approaches at almost vertical incidence, the ionized layer is unable to return it to earth.

If transmission is made at vertical incidence (straight up) and the frequency continues to increase, the lower frequencies will be returned to earth: but eventually a point will be reached where the signals are not returned. The highest frequency that will be returned from the vertical incidence is called the critical frequency, which will vary with the seasons, time of day, or any other effects which cause the density of the ionosphere to change. The critical frequency is higher in the daytime than at night.

Maximum Usable Frequency

As the incident angle is lowered from the vertical, there is a corresponding increase in the frequency which will be returned to earth. The factors which determine the actual frequency to be used for a communication circuit are the height of the ionized layer used for refraction and the distance between the two ends of the circuit. The maximum frequency which will be refracted for a given distance of transmission is called the maximum usable frequency (MUF). The MUF is always higher than the critical frequency.

Frequency of Optimum Traffic

Experience has shown that the MUF may increase or decrease significantly, especially during daytime because of changes occuring in the ionosphere. Therefore, the frequency of optimum traffic (FOT), which is computed as 0.85 times the MUF, is used so that variations in the ionosphere will have less effect on the communication circuit. For example, the FOT of 10,000 kc (MUF) would be 8500 kc. Since the maximum usable frequency may be lowered by sudden variations in the ionosphere, radio signals of 10,000 kc may be absorbed or refracted back to earth short of the intended receiving site. However, by use of 8500 kc (FOT) communications would not be interrupted.

ABSORPTION IN THE IONOSPHERE

As the radio wave passes into the ionosphere, it loses some of its energy to the free electrons and ions. If those high-energy free electrons and ions do not collide with gas molecules of low energy, most of the energy lost by the radio wave is reconverted into electromagnetic energy, and the wave continues to be propagated with little change in intensity. However, if the high-energy free electrons and ions do collide with other particles, they dissipate the energy which they have acquired from the wave, resulting in absorption of the energy from the wave. Since absorption of energy is dependent upon collision of particles, the greater the density of the ionized layer, the greater the probability of collisions; therefore the greater the absorption. The highly dense D and E layers provide the greatest absorption for the ionospheric wave.

Because the amount of attenuation of the sky wave depends upon the density of the ionosphere, which varies with seasonal and daily conditions, it is impossible to express a fixed relationship between distance and signal strength for ionospheric propagation. Under favorable conditions, only free-space attenuation will occur. Under certain conditions, the absorption of energy is so great that communicating over any distance beyond the line of sight is difficult. Sky-wave intensity varies from minute to minute, month to month, and year to year because of variations in the ionosphere.

FADING

Fading is the variation of radio signal strength at a radio receiver during the time of reception. Signals received over an ionospheric path may vary in intensity over short periods of time. There are three major reasons for fading. When the radio wave is refracted in the ionosphere or reflected from the earth's surface, random variations in polarization of the wave may occur, causing changes in the received signal level because of the inability of the antenna to receive polarization changes. Fading may also occur if the FOT is selected too close to the MUF. If this is the case, any slight change in the ionosphere might cause a change in signal strength or refract the wave far short of or beyond the intended receiving site. However, the major reason for fading on ionospheric circuits is caused by multipath propagation, which is next described.

Multipath Fading

Figure 10-8 shows the various paths a signal can travel between two sites in a typical circuit.

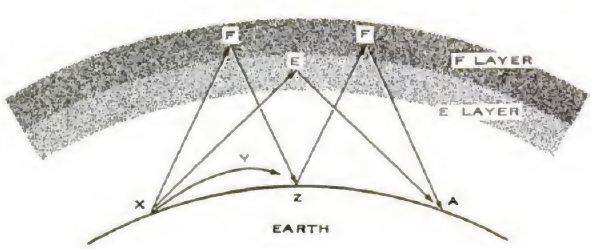

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Figure 10-8.—Multipath transmission.

One signal from the transmitter may follow the path XYZ, which is the basic ground wave. Another signal, which follows the path XEA, is refracted from the E layer and received at A, but not at Z. Still another path is XFZFA, which results from a greater angle of incidence and two refractions from the F layer. At point Z, the received signal is a combination of the ground wave and the sky wave. If these two waves are received out of phase, they will produce a weak or fading signal. If they are received in phase, they will produce a stronger signal. Small alterations in the transmission path may change the phase relationship of the two signals, causing periodic fading. This same addition of signal components occurs at point A. At this point, the double-hop F layer signal may be in or out of phase with the signal arriving from the E layer.

SELECTIVE FADING.—Fading resulting from multipath propagation is variable with frequency since each frequency arrives at the receiving point via a different radio path. When a wide band of frequencies, such as multichannel single sideband, is transmitted, the frequencies in the sideband will vary in the amount (if any) of fading. This variation is called selective fading. When selective fading occurs, all frequencies within the envelope of the transmitted signal may not retain their original phases and relative amplitudes. This fading may cause severe distortion of the signal and limit the total bandwidth which can be transmitted.

SKY-WAVE TRANSMISSION PATHS

Figure 10-9 illustrates some of the many possible paths that radio waves of various frequencies may take between a transmitter and a receiver by refraction in the ionosphere. Note that some of the waves, which in this case are assumed to be of too high a frequency (30 mc and higher) for refraction by the ionized layer, pass on through and are lost in space. Other components of the wave, which are assumed to be of the correct frequency (below 30 mc) for refraction from the ionospheric layers, are returned to the earth; these waves provide communications. Note also that the skip distance is the distance from the transmitter to the nearest point at which the refracted waves return to earth. The skip zone and its relation to the ground wave are shown in figure 10-9.

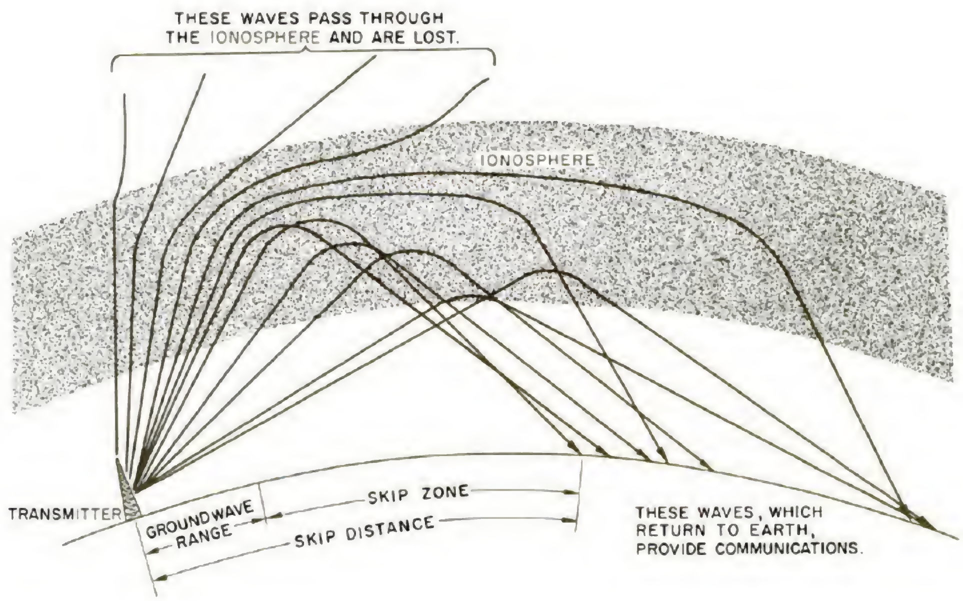

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Figure 10-9.—Various sky-wave transmission paths.

Note the distinction between the terms SKIP DISTANCE AND SKIP ZONE. For each frequency at which refraction from an ionospheric layer takes place, there is a skip distance that depends on the degree of ionization present. The skip zone, on the other hand, depends on how far the ground wave extends from the transmitter and where the sky wave first returns to earth by refraction from an ionized layer. The skip zone is the zone between the end of the ground wave transmission and the point on the earth where the sky wave first returns from the ionosphere.

As noted previously in the discussion of the ionosphere, the higher the frequency of a wave, the less it is refracted by a given degree of ionization. Figure 10-10 shows three separate waves of different frequencies entering an ionospheric layer at the same angle. The 100-mc wave is not refracted sufficiently by the ionosphere and is not returned, but the 20-mc wave, refracted less than the 5-mc wave, returns at a greater distance from the transmitter.

IONOSPHERIC SCATTER

In explaining refraction and describing the ionosphere, it has been assumed that the density variation within a layer is gradual and uniform. This picture of the ionosphere provides a very satisfactory explanation for most radio wave phenomena associated with the atmosphere. However, there are also turbulent and irregular variations in the ion density of the ionosphere. These variations result in the scattering of the radio wave. In areas where scattering is quite predominant most of the year, point to point scatter communications can be accomplished by utilizing high-power transmitters. Figure 10-11 illustrates how scattering can occur. When a wavefront encounters a sudden change in ion density, irregular variations in the wavefront result. Scattering of radio energy by the ionosphere is similar to the scattering of light by small water droplets in a cloud or fog. When a beam of light shines through the mist, moving points of light are seen in the beam. These are caused by water droplets which scatter light to the observer.

Scattering takes place in the E layer region of the ionosphere. Under suitable conditions, this type of propagation may be used for low transmitting angles with frequencies as high as 100 mc. Ordinarily, radio waves with frequencies up to about 30 mc will pass directly through the E layers and be refracted from the F layer.

However, the scattering process causes some of this energy to be returned from the E layer to the receiving antenna. Only a very small percentage of the toal energy is returned. If the scattering region is within visible range of the transmitting and receiving antennas, the total loss is free-space loss, plus a scatter loss, which is dependent upon the size and strength of the irregular variation in the medium and the angular change in direction of the wavefront. This scatter loss is large—in the range of 60 to 100 or more db. Since the scatter loss is so large, this form of propagation requires the use of high-power transmitters and highly directional antennas.

Signals received over ionospheric scatter circuits are quite weak, but do not show the extreme changes in signal level (fading) which sometimes occur with other types of propagation. In a daily cycle, the signal level reaches a minimum value at about 2000 local time. There is, however, no nighttime disappearance of the signal as in the case of regular E layer propagation which disappears shortly after sunset. There is also an annual cycle with minimum field strength or signal level during spring and fall. The received signal is also characterized by rapid, punctuated strong bursts of energy evidently associated with ionized meteor trails. (Meteor trails are treated in a later section.)

The principal factors which limit the utilization of ionospheric scatter are frequency and distance. The useful frequency range for ionospheric scatter extends from about 20 to 60 mc. The region in which the scattering occurs is fixed at an approximate height of about 60 miles which determines the optimum range of distance which is about 500 to 1100 miles.

IONOSPHERIC PROPAGATION SUMMARY

The ionospheric wave is that part of the total radiated energy which is propagated upward and returned to the earth by refraction or scattering in the ionosphere. The ionosphere is not a stable region, but changes in height, thickness, and density with the time of day, the seasons, and the cyclic sunspot variations in the sun. The changes affect the received signal level. The ionospheric method of propagation is also frequency sensitive. Low frequencies suffer high absorption; frequencies above the critical frequency penetrate the ionosphere and are not returned to earth.

The maximum useful frequency (MUF) is the highest frequency which will be returned to the receiving site over the operating circuit.

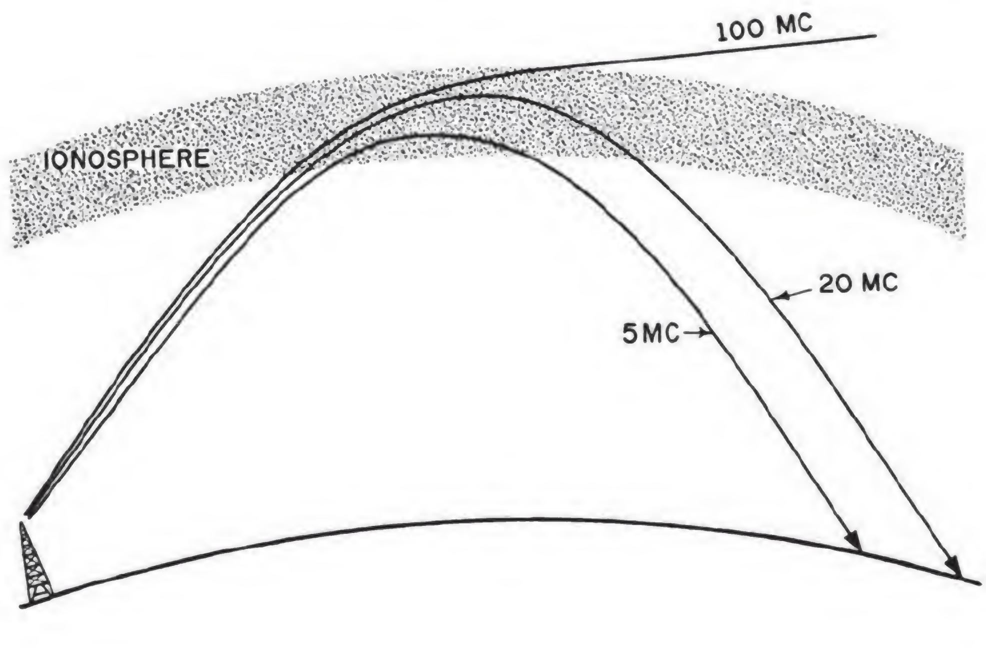

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Figure 10-10.—Frequency versus distance for returned waves.

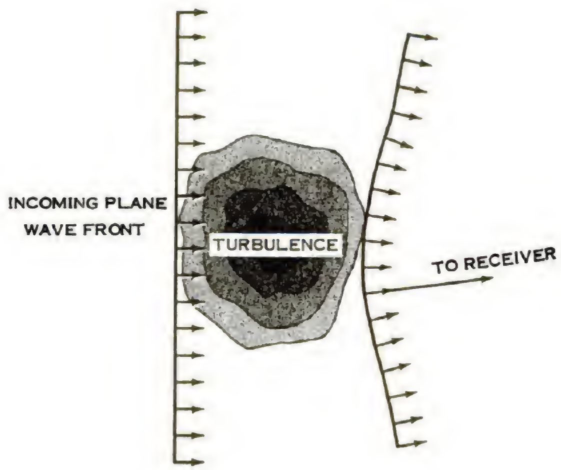

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Figure 10-11.—Variation in wavefront which results in scattering.

A frequency slightly less than the maximum usable frequency is normally selected for use on a circuit. This is called the frequency of optimum traffic (FOT). If it is too high, the circuit will be unreliable since the received level will be too dependent upon minor changes in the ionosphere. If the selected frequency is too low. the signal will suffer high absorption in the lower region of the ionosphere.

GROUND-WAVE PROPAGATION

The ground wave is that part of the total radiated energy which is propagated at a low angle from the transmitting antenna and travels close to the earth. The ground wave includes components traveling in actual contact with the earth as well as components which travel directly from the transmitting antenna to the receiving antenna when the two antennas are high enough from the ground so that they can "see" each other. For purposes of discussion, ground waves are assumed not to be propagated via the ionosphere. The two components of a ground wave are the surface wave and the space wave.

SURFACE WAVE

A radio wave that travels in CONTACT with the earth's surface is called a surface wave. It is the type of wave which provides reception up to a distance of 100 miles or more in the standard commercial broadcast band during the daytime. Because attenuation of this type of radio wave is very high, its intensity drops off rapidly with increased distance from the transmitter. A surface wave must be essentially vertically polarized because a horizontally polarized wave traveling in contact with the earth is completely attenuated only a short distance away from the transmitter. The transmitting and receiving antennas, therefore, must generate and receive vertically polarized waves if the surface wave is to be utilized to advantage. In general terms, this means that both antennas must be vertical.

Table 10-2. —Relative Conductivity.

SURFACE	RELATIVE CONDUCTIVITY
Sea water	Good
Flat, loamy soil	Fair
Large bodies of fresh water	Fair
Rocky terrain	Poor
Desert	Poor
Jungle	Unusable

Attenuation of the surface wave due to absorption depends upon the condition of the earth's surface and the transmitted frequency. Table 10-2 gives the relative conductivity of various earth surfaces. From this table, it is apparent that the best surface-wave transmission occurs over sea water and that the highest degree of attenuation is found over jungle areas. Attenuation over all types of terrain increases rapidly as the frequency is increased.

Extremely high losses make it impractical to use the surface wave for long-distance transmissions with frequencies above 1500 kc. However, by lowering the transmitting frequency into the VLF range and using very high-powered transmitters, the surface wave can be propagated great distances. High-powered VLF transmitters can provide coverage to naval units operating anywhere at sea. The phenomenon which permits propagation of surface waves far beyond the radio horizon is called diffraction, or the ability of a radio wave to bend around obstacles in its path. Thus, the Navy's extremely high-powered VLF transmitters are actually capable of transmitting surface wave signals around the earth.

SPACE WAVE

While the characteristics of the surface wave serve to explain propagation, along the earth's surface, of signals in the VLF to HF frequency ranges, they do not seem to apply to reception of higher frequencies within and slightly beyond the radio horizon. Such signals are considered to be propagated via the space wave.

Space waves travel close to but not in contact with the earth, directly from transmitting to receiving antenna. Consequently, the receiving antenna must be situated within the radio horizon of the transmitting antenna. Because radio waves are refracted or bent slightly even when propagated through the troposphere well below the ionosphere, the radio horizon is actually about four-thirds times the line-of-sight or natural horizon.

Figure 10-12 illustrates space-wave propagation of a low-powered VHF signal. Due to heavy absorption at frequencies above 1500 kc, surface-wave propagation could not be used to maintain such a circuit. However, because it is not in direct contact with the earth, the space wave is not attenuated greatly and will arrive at the receiving antenna with minimum loss of signal strength.

In figure 10-12, note the shaded area beyond the radio horizon of the transmitting antenna. Reception of the space-wave signal in this area is made possible because the space wave is diffracted over the surface of the earth. However, because space-wave signals are usually in the VHF and higher frequency bands and are transmitted using low power, their reception in the "diffraction" zone normally is limited to a few miles beyond the radio horizon. An exception to this rule is caused by the phenomenon called temperature inversion, which will be discussed in a later section.

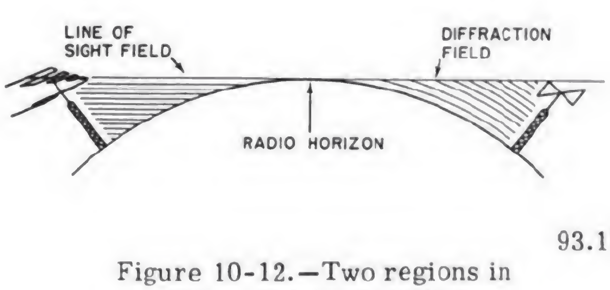

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Figure 10-12.—Two regions in space-wave propagation.

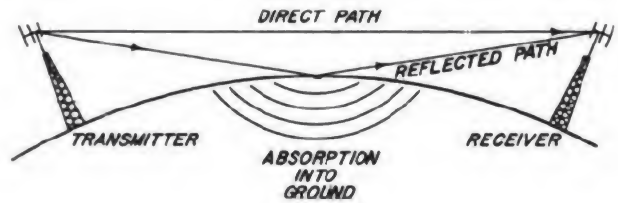

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Figure 10-13.—Possible routes for ground waves.

Although space waves suffer little ground attenuation, they are susceptible to fading. Unless the space wave is transmitted by a highly directional, narrow-beam antenna, some of its energy may be directed obliquely towards the ground and subsequently be reflected towards the receiving antenna as illustrated in figure 10-13. That ground-reflected component of the space wave will undergo both a phase shift and partial absorption as it is reflected by the ground. Consequently, the signal which is finally received will be a combination of the direct space wave and the weaker, out-of-phase ground-reflected wave. This combination will cause the received signal to fade in varying degrees depending upon the phase of difference of the two incoming waves. A phase difference of 180 degrees will produce almost complete fading.

WEATHER VERSUS PROPAGATION

Weather is one of the many factors affecting wave propagation. Because there are many ways in which weather may affect wave propagation, it is the purpose of this section to consider the various phenomena and to show their relationship to radio wave propagation.

Wind, air temperature, and water content of the air can combine in may ways, with different combinations causing radio signals to be heard hundreds of miles beyond their ordinary range or to be attenuated to a point where the signals may not be picked up over a normally satisfactory path. Unfortunately, no hard and fast rules may be given concerning the effects of weather on radio transmissions since the variables of weather are extremely complex and subject to frequent change. Any discussion of the effects of weather on radio must therefore

be limited to general terms and will be so treated here.

PRECIPITATION ATTENUATION

Calculating the effect of weather on radio propagation would be comparatively simple if there were neither water nor water vapor in the atmosphere. However, some form of water (vapor, liquid, or solid) is always present in the atmosphere, even in arid regions and must be considered in all microwave calculations.

Rain

Attenuation due to raindrops is greater than attenuation due to other forms of water. Attenuation may be caused by absorption, whereby the raindrop, acting as a poor dielectric, absorbs power from the electromagnetic wave and dissipates the power by heat loss or by scattering. Raindrops will cause greater attenuation by scattering than by absorption at frequencies above 100 mc and at frequencies above 6 gc attenuation by raindrop scatter is quite pronounced.

Variation in raindrop size causes one of the difficulties in attempting to determine the attenuation by scattering. There is no uniformity of drop size in any rainfall; the droplets vary in diameter from less than one millimeter to five millimeters or more. As a general rule, the heaviest rate of rainfall is accompanied by the greatest drop size, and, therefore, the greatest attenuation.

Fog

As far as attenuation is concerned, fog may be considered another form of rain. Since fog remains suspended in the atmosphere, the attenuation to be expected is determined by the quantity of water per unit volume and by the size of the droplets. Attenuation due to fog is of minor importance at frequencies lower than 2 gc. Fog can cause serious attenuation by absorption, but only at frequencies above 2 gc.

Snow

Scattering due to snow is difficult to compute, owing to the irregularities of the flakes. While information on the attenuating effect of snow is limited, it is probable that attenuation from snow is less than from rain falling at an equal rate. This assumption is borne out by the fact that the density of rain is eight times the density of snow. As a result, a rainfall of one inch per hour, for example, would have far more water per cubic meter of atmosphere than an equal snowfall.

Hail

Attenuation by hail is determined by the size of the stones and their density. Attenuation of electromagnetic waves by scattering due to hailstones is considerably less than by rain since ice has a lower index of refraction.

Sleet and Glaze

Sleet is defined meteorologically as very small pellets of ice, and as such has little effect on the electromagnetic wave in the frequency limits discussed in this chapter. Glaze, defined meteorologically as rain that freezes on contact with any object, may be safely treated as rain of equal drop size.

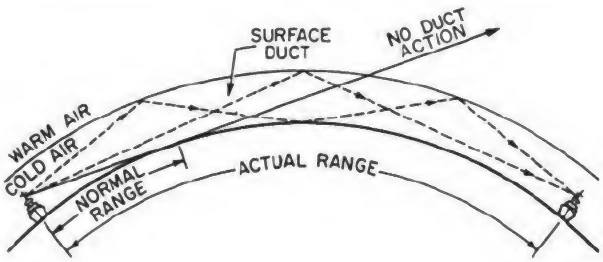
DUCTING

Unusual ranges of VHF and UHF signals are caused by abnormal atmospheric conditions a few miles above the earth. Normally, the warmest air is found near the surface of the water. The air gradually becomes cooler as altitude increases. Sometimes unusual situations develop where warm layers of air are found above cooler layers. This condition is known as TEMPERATURE INVERSION.

When a temperature inversion exists, the amount of refraction is different for the particles trapped within the boundaries from those outside them. These differences form channels or ducts that will conduct the radio waves many miles beyond the assumed normal range.

Sometimes these ducts are in contact with the water and may extend a few hundred feet into the air. At other times the duct will start at an elevation of between 500 and 1000 feet and extend an additional 500 to 1000 feet in the air.

If an antenna extends into the duct or if the wave enters a duct after leaving an antenna, the transmission may be conducted a long distance. An example of this type of transmission of radio waves in ducts formed by temperature inversions is shown in figure 10-14.



20.255
Figure 10-14.—Dust effect in high-frequency transmissions.

With certain exceptions, ducts are formed over water where the following conditions are observed aboard ship:

1. A wind is blowing from land.
2. There is a stratum of quiet air.
3. There are clear skies, little wind, and high barometric conditions.
4. A cool breeze is blowing over warm open ocean, especially in the tropic areas and in the trade-wind belt.
5. Smoke, haze, or dust fails to rise, but spreads out horizontally.

TROPOSPHERIC SCATTER PROPAGATION

The foregoing sections of this chapter have provided a discussion of that portion of radiated energy which is acted upon by the ionosphere and returned to earth and also that portion of radiated energy which is propagated along the earth's surface. In this section, consideration is given to that part of the total radiated energy which undergoes reflections and refractions in the troposphere.

APPLICATION OF TROPOSPHERIC SCATTER

When a space wave (one part of the ground wave) is transmitted, it undergoes very little attenuation within line-of-sight distance. When the horizon is reached, the wave is diffracted and follows the earth's curvature. The rate of attenuation increases very rapidly for distances beyond the horizon, and signals in the diffraction field are extremely weak. Tropospheric scatter provides a usable signal at distances beyond the point where the diffraction field drops below a usable level. The scattered wave is able to reach beyond the diffraction field because of the height at which the scattering takes place. The tropospheric region, which contributes most strongly to the scatter field lies near the midpoint of the circuit and just above the radio horizon of the antenna.

Tropospheric scatter propagation is used for point-to-point communications. A correctly designed tropospheric scatter circuit will provide highly reliable service for distances ranging from 50 miles to 500 miles. A tropospheric scatter circuit is not affected by ionospheric and auroral disturbances. The usable frequency range extends from approximately 100 mc to 10 gc.

CHARACTERISTICS OF THE TROPOSPHERE

The troposphere is the lowest region of the atmosphere, extending from the ground to a height of slightly over six miles. Virtually all weather phenomena occur in this region of the atmosphere. There is practically no ionization in the troposphere. Generally, the troposphere is characterized by a steady decrease of temperature and pressure with an increase in height.

Refraction of radio waves in the troposphere is a function of various meteorological variables. Because of the uneven heating of the earth's surface, the air in the troposphere is in constant motion. This motion causes small turbulences, or eddies, to be formed. These turbulences are quite similar to the whirlpools in a rapidly moving stream of water. The turbulence is most intense near the earth's surface and gradually diminishes with altitude.

For frequencies up to about 30 mc, radio wavelengths are large compared to the size of the turbulences; therefore, the turbulences have little effect on the transmitted signal. However, as the frequency is increased, these local turbulences become increasingly important because they are responsible for tropospheric scatter transmission.

TROPOSPHERIC SCATTERING

When a wavefront passing through the troposphere encounters a turbulence, a small amount of energy is scattered away from the incident wave. The scatter effect is the same as if each turbulence received the signal and reradiated it. Thus the effect is similar to the ionospheric scatter shown in figure 10-11. The total received

signal is an accumulation of the energy received from each one of the turbulences.

The word "scatter" implies that the spreading of energy is equal in all directions; however, the direction of energy distribution in tropospheric scatter propagation differs only slightly from the direction of the path of the main wavefront. The scattering occurs chiefly in the forward direction; therefore the term "forward scatter" is sometimes used when talking about tropospheric scatter.

The magnitude of the received signal depends on the number of turbulences causing scatter in the desired direction and the direction and gain of the receiving antenna beam. This quantity or magnitude is called the scatter volume. The scatter volume and scatter angle are shown in figure 10-15. As the scatter angle is increased, the amount of received scattered energy decreases very rapidly.

The amount of received energy decreases as the height of the scatter volume is increased. There are two reasons for this: (1) scatter angle increases as height is increased; (2) the amount of turbulence decreases with height. As the circuit distance is increased, the height of the scatter volume must also be increased. Therefore, the received signal level decreases as the circuit distance is increased.

Since tropospheric scatter depends on turbulence in the atmosphere, changes in atmospheric conditions will affect the received signal level. Both daily and seasonal variations are noted. These changes are called long-term fading. In addition to long-term fading, the tropospheric scatter signal often is also characterized by very rapid fading which is caused by multipath propagation. The signals received at any one time are the sum of all the signals received from each of the turbulences in the volume.

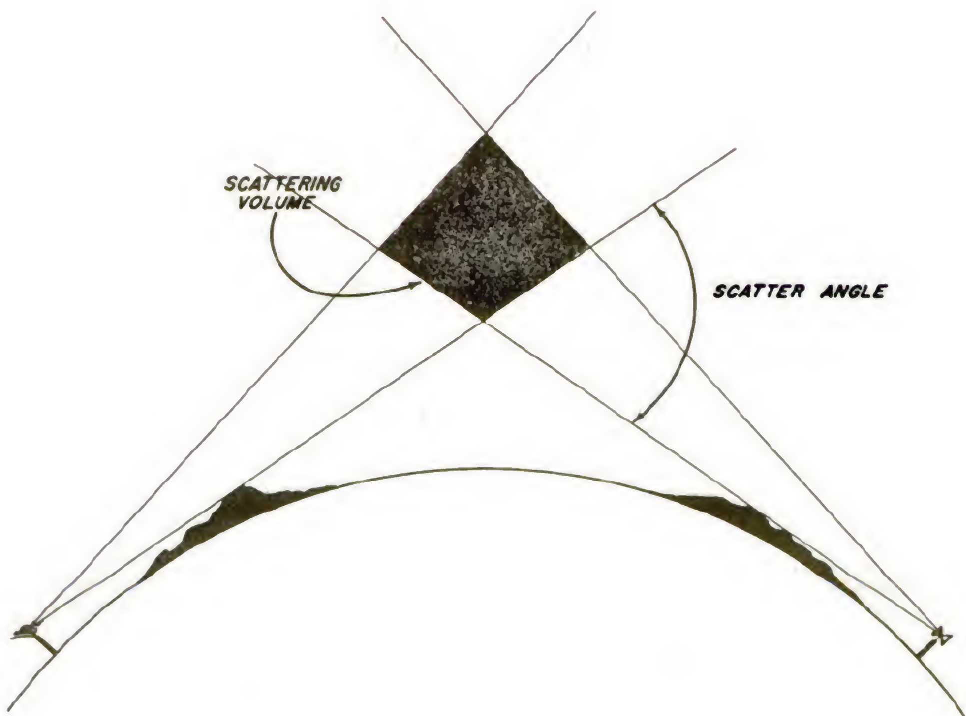


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Figure 10-15.—Geometry of tropospheric scattering.

Since the turbulent condition is constantly changing, the path lengths and individual signal levels are also changing, resulting in a rapidly changing signal. Although the signal level is constantly changing, the average signal level is persistent, and no complete fade-out occurs.

Another characteristic of a tropospheric scatter signal is its relatively low power level. The scatter volume can be pictured as a relay station, located above the horizon, receiving the transmitted energy and reradiating it to some point beyond the line-of-sight distance. Since most of the transmitted energy is not reradiated to the receiver, the efficiency is very low, and the signal level at the final receiver point is low. To compensate for the low efficiency in the scatter volume, the incident power must be high. This is accomplished by using high-power transmitters and high-gain antennas which concentrate the transmitted power into a beam, thus increasing the intensity of energy on each turbulence in the volume. The receiver must also be very sensitive to detect the low-level signals.

Several factors determine the frequency range most suitable for tropospheric scatter. For frequencies below 30 mc, the troposphere appears to be uniform, and scattering does not occur. Also, at these lower frequencies (longer wavelengths), it is difficult to construct the required high-gain antennas because of their large size. As the frequency is increased, the amount of scattering loss and the free-space loss increases. Above 10 gc, the wave is greatly affected by atmospheric conditions.

METEOR-BURST PROPAGATION

Meteor-burst propagation can be considered in a separate category from ionospheric and tropospheric propagation. Basically, meteor-burst propagation is accomplished by bouncing a transmitted radio wave off the ion trail of a single meteor and back to earth.

Many hundreds of meteors enter the earth's atmosphere daily. Almost all of them disintegrate and vaporize because of the high heat which is caused by the friction of the meteor's passage through the earth's atmosphere. The heat vaporization causes the meteor to leave a trail of ionized particles behind it. Such trails can be thought of as cylindrical patterns of ionization. Initially, the cylinders are very small, but they expand quickly and within approximately one- or two-tenths of a second are absorbed by the surrounding atmosphere. The rates at which these meteor trails become available vary greatly, 120 per minute being a representative figure. The area of the atmosphere in which meteors ionize into trails is quite well defined between heights of 50 to 75 miles, or at approximately the lower part of the E layer.

The conditions for successful meteor-burst propagation are met by only about five percent of the meteors which enter the earth's atmosphere. Consequently, sensitive devices must continually monitor that portion of the ionosphere and "trigger" the transmitter only when a suitable meteor burst comes into a position appropriate for proper signal transmission. Thus a message transmitted by meteor-burst propagation usually is transmitted in a series of short bursts, each of which utilizes only one meteor trail. Communication links using meteor-burst propagation are normally limited to about 1000 miles. Frequencies suitable for this method of transmission are in the 6- to 100-mc range.

FREQUENCY CHARACTERISTICS

For all practical purposes it is convenient to classify radio waves into band or frequencies. Each band of frequencies has similar propagation effects. However, any such classification must be of a general nature only since changes in propagation characteristics with changes in frequency are not sharply defined. Thus when an upper or lower limit of frequency is designated for a certain propagation effect, it does not mean that such an effect stops at those limits, but rather that it becomes negligible beyond such limits.

UPPER MF BAND

In the foregoing discussion of propagation, the upper MF band (the 1- to 4-mc region) received little attention since its role in communications is that of short haul (400 miles), reliable, point-to-point circuits. In general, the attenuation is so high as to make transmission beyond 400 miles almost out of the question or at least so unreliable as to be considered of only secondary importance. Usually this band, because of the rather long antennas required, utilizes horizontal wire antennas where antenna space is unrestricted. In mobile application, whip antennas are used exclusively in this frequency range.

Sunspot activity ordinarily has only small effects in the 1- to 4-mc range. When sunspot activity is high, attenuation increases and circuit reliability decreases. However, when sunspot activity is low, the reliability of these circuits maintains a more uniform character since attenuation is reduced. The sunspot maximum experienced during 1958 constituted the highest peak in activity in the history of radio. The Solar Observatory at Zurich, Switzerland, which has been following the fluctuations in sunspot numbers since 1750, indicated that the 1958 peak was one of the highest ever observed.

Of particular interest now is the fact that this same cycle should take on its lowest value of sunspot activity during the 1964-65 time period. Best expert opinion predicts a situation during this period when the sunspot numbers will reach a new low for the history of radio. Smooth sunspot numbers as low as one or two are predicted as compared to the previous low (3 to 5) of the 1912-13 period. With the coming of the lower sunspot numbers during the next few years (optimum conditions occurring during the winter of 1965), increased propagation ranges will result in the 1- to 4-mc frequency range due to lower ionospheric absorption which will be present at that time. Communication ranges from 400 miles to 1200 miles should be possible during this period.

HF BAND

The range of frequencies designated as the HF band (3 to 30 mc) employs ionospheric propagation for long-range sky wave communication. The frequency characteristics and propagation effects were discussed earlier under ionospheric propagation.

VHF BAND

The VHF band (30 to 300 mc) is part of the oldest known frequency band of the entire radio spectrum; both Hertz and Marconi conducted their famous experiments in the region from 30 to 3000 mc. As a rule, ionospheric propagation is negligible in the VHF band and cannot be relied upon for propagation to great distances. However, irregular ionospheric refractions are possible (due to sporadic E variations) and can cause a signal in the lower part of the band to be propagated several hundred miles by the ionosphere. Propagation by way of the sporadic E layer is such that scattering or refraction decreases rapidly with an increase in frequency and becomes of little importance above 100 mc.

The most common path of propagation used at VHF frequencies is, therefore, through the troposphere and along the surface of the earth. Since the density of the earth's atmosphere normally decreases with altitude, radio waves are propagated by refraction along a curved path to a distance approximating four-thirds the earth's true horizon. In this frequency range, the radio horizon (four-thirds of the true horizon) is governed not only by refraction but by diffraction as well.

Diffraction plays a major role in the VHF band, depending upon the path over which the waves are propagated. The effect of obstacle gain, caused by diffraction of radio waves over a mountain ridge, was first discovered in this frequency range. Diffraction effects are primarily important with regard to irregular terrain which makes possible the reception of signals in the geometric shadow region of a hill or other intervening object. Generally the higher the frequency, the less the diffraction effects.

Atmospheric noise at these frequencies is fairly low and decreases with increasing frequency. Such noise usually originates only in local electrical storms. However, one of the more important sources of noise in this range is man-made noise such as that from ignition systems, diathermy machines, and X-ray equipment. In this range, receiver noise also begins to become prevalent, although considerable improvement in circuit design has made possible its reduction.

UHF BAND

Almost all the energy transmitted from point to point in the UHF band (300 to 3000 mc) is propagated through the earth's troposphere along a curved path. The refracted path may again be assumed to be a straight line path extending to distances of four-thirds times the true horizon. However, the transmission range may be extended several hundred miles further by means of tropospheric scatter propagation.

Ground reflections are still present at ultrahigh frequencies and can cause multipath fading due to destructive interference, although such reflections become of less importance at the higher frequencies of this band. However, a second type of multipath fading can occur when parts of the wave are refracted through other higher layers of the atmosphere and become bent sufficiently to return and combine with the wave received over a lower and more direct path.

At frequencies above 1000 mc, attenuation of the transmitted signal by trees or other vegetation can range anywhere from 12 to 46 db per mile. However, if the antennas are located to give first Fresnel zone (wave interference zone) clearance above the trees, such attenuation becomes negligible.

Atmospheric and man-made noise in this frequency band is extremely low, with the exception of ignition pulses which can become serious at times. Receiver noise is somewhat greater at these frequencies and increases with increasing frequency, thus calling for special receiving tubes and circuit design.

LOWER SHF BAND

At the frequencies of the lower SHF band (3 to 13 gc), transmission is generally limited to line-of-sight distances based on four-thirds the true horizon. Very little wave reflection will radiate from the earth at these frequencies. Instead, the earth will act as if it were made up of an infinite number of small mirrors, each reflecting the incident wave in a different direction. This phenomenon is sometimes called diffuse reflection. In addition, incident radiation will also be absorbed by the earth's vegetation. The amount of reflected energy from the earth's surface is small; consequently very little wave interference will occur from that source. However, multipath fading and refraction by several propagation paths through the atmosphere is important throughout the entire band. There is also a tendency for buildings and other man-made objects to cast sharp shadows at these frequencies and, if the surface of such objects is smooth, they will reflect the waves in a new direction.

Rain scattering and absorption can cause a serious loss of radiated power at the higher end of this frequency range. If the drop size is comparable to the wavelength of the propagated wave, a very substantial portion of the transmitted energy will be reradiated from the raindrop in a wide range direction. This phenomenon, known as scattering, has an attenuating effect on radio waves, an effect somewhat like that of diffuse earth reflections. However, not all the energy incident upon a raindrop is reradiated; instead, it is virtually trapped or absorbed and converted into heat. If the drop size is comparatively small in relation to the wavelength, such losses are dependent only upon the volume of water in suspension and therefore are generally negligible.

The use of sharply beamed waves to overcome the losses due to atmospheric attenuation in this band conserves enough power to enable a few watts of directed power to be as effective at a distant receiver as many kilowatts of undirected power.

Receiver noise at these superhigh frequencies has a significant effect on the practical range of a receiving system. Special techniques—such as the use of crystal mixers, MASERS, transistors, and high frequency pumps—have been developed to minimize the noise by converting the received signal to a lower frequency before amplification.

SATELLITE COMMUNICATIONS

One of the new types of communications in the SHF band is satellite relay communications—a system of long range communications whereby shore-based transceiver sites communicate via satellite relay. One of the first successful attempts in this field of communications was Bell Laboratories' TELSTAR, so named by combining the words "telecommunication" and "star." The satellite was designed and developed to relay telephone, television, and telegraph messages across the Atlantic.

The SHF band is used in this field of communication for several reasons. This band is not affected by the ionosphere and is not subject to the sun's ionospheric storms and sudden ionospheric disturbances. Also the band has a low noise figure and is free of the crowded signal conditions in lower bands. Another advantage of using the superhigh frequencies is that the small antennas required for

transmitting and receiving can be constructed of light material which adds little weight to the satellite.

The attenuation of the satellite's signal is essentially that of a wave traveling in free space; but because of the limited satellite weight and therefore limited transmitter power, the signal level is very low when it reaches earth. TELSTAR's transmitter power output is about two to three watts and the signal received at earth is about one trillionth of a watt. This low level of signal presented a difficult problem that had to be solved before the system could be put in operation.

The solution of this problem was greatly facilitated by the development of man-made rubies called MASERS and large horn-type receiving antennas which are used to amplify the weak signals several thousand times. Amplifying energy comes from the chromium atoms in the ruby which is operated at a very low temperature of minus 456 degrees Fahrenheit. The MASER, when operated in this manner, will amplify the weak signal without producing noise or amplifying adjacent interference. MASER is the short form of the designation, Microwave Amplification by Stimulated Emission of Radiation.

The propagation path for this type of operation is direct line of sight and is usable in any direction except the first few degrees above the horizon. The tropospheric scatter angle must be passed before the signal level from the satellite is usable because of the high attenuation offered at low angles above the horizon.

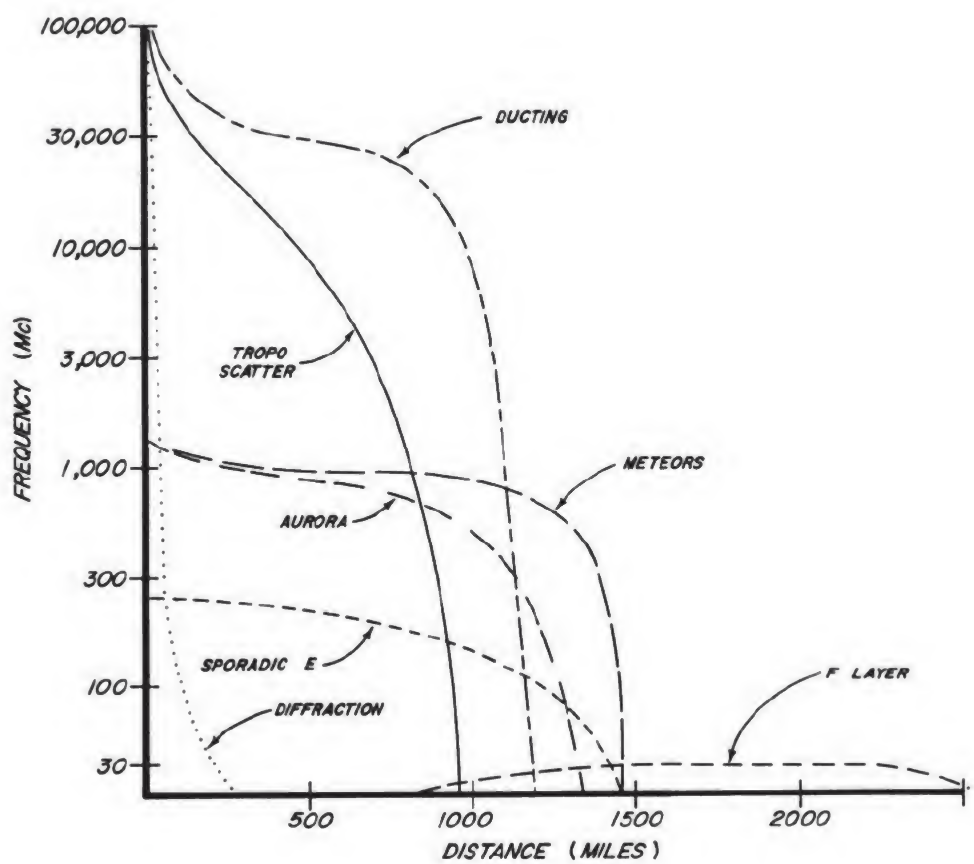

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Figure 10-16.—Propagation ranges above 30 mc.

LASER

The ever increasing need for more communications channels has resulted in new approaches to this communication problem. The optical LASER (Light Amplification by Stimulated Emission of Radiation) is one of the most recent and dramatic developments in communications. The first LASER's were man-made rubies. It was found that under certain conditions a precisely shaped ruby when excited by electrical energy would emit a sharply defined red-light beam. With the ruby LASER, visible light in the red color spectrum (4×10^{14} cps) can be transmitted across considerable distances with high intensity, an extremely small beam, and with little loss of power. Further experiments have led to other types of LASER's and LASER producing devices.

The propagation properties of the LASER are the same as those for all visible light. The LASER beam can be reflected, refracted, and diffracted in the lower atmosphere (troposphere) in much the same way as any electromagnetic transmission above 13 gc. Rain, snow, and mist will have a great effect on transmission along the earth's surface by attenuation through diffraction and absorption.

LASERS have been modulated with frequencies as high as 11 gc producing a bandwidth wide enough to accommodate millions of communications channels.

Because of the small power losses in high-energy LASER beams traveling beyond the earth's troposphere, it is anticipated that a LASER with a small two- or three-inch initial beam could be used to communicate directly from the earth to Mars. Further research with LASERS undoubtedly will lead to many other applications.

PROPAGATION RANGES ABOVE 30 MC

The approximate ranges for radio transmissions propagated via various media at frequencies above 30 mc are illustrated in figure 10-16. The ranges given are calculated for average atmospheric conditions and will vary as conditions change.

It should be noted that the Aurora propagation phenomena will occur only during an ionospheric magnetic storm. Also, the ducting propagation phenomena will occur only during a temperature inversion which exists along the path between the transmitting and receiving ends of a circuit. For the other propagation media (troposcatter, diffraction, etc.), the ranges will exist most of the time under average conditions.

CHAPTER 11

ANTENNAS, TRANSMISSION LINES, AND MULTICOUPLERS

As a CT M, you will be primarily concerned with receiving antennas and antenna arrays. You have perhaps noticed when reading about antennas that the discussion is usually written from the standpoint of antennas used with a transmitter. However, by a theorem called the reciprocity theorem, the electrical characteristics of a receiving antenna are the same as if the antenna were used for transmitting. Therefore, if it is necessary to find the electrical characteristics of a receiving antenna (radiation resistance, lobe patterns, etc.) the computations are performed in the same manner as though the antenna were used for transmitting. The basic concepts required for the consideration of antennas and propagation can be found in Basic Electronics, NavPers 10087-A.

When actually designing a receiving antenna the design criteria will be different from those used when designing a transmitting antenna. The difference in criteria stems from the fact that transmitting antennas are primarily designed to be "impedance matchers" and receiving antennas are not. A transmitting antenna is designed to provide the proper impedance matching to obtain the most efficient transfer of power at the transmitter output terminals to power in space. If the same antenna were used with a receiver, it would provide the most efficient coupling possible to transfer the energy from space to the input terminals of the receiver. This is not necessarily the most important consideraton for a receiver, however; for reception purposes the primary consideration is usually to obtain the highest possible signal-to-noise ratio.

As a result of the consideration just described, transmitting antennas will have to be carefully tuned, carefully coupled to the transmitter, and operated in a relatively narrow frequency band in order to achieve efficient operation. Receiving antennas do not have to be as carefully tuned and can generally operate over relatively broad frequency bands.

REVIEW OF TERMS

Wavelength

The wavelength, λ, of a radio wave (in meters) is equal to its velocity in free space (300,000,000 meters per second) divided by its frequency, f, in CYCLES per second. That is,

$$\lambda = \frac{300,000,000}{f}$$

When the frequency is in KILOCYCLES per second, the formula becomes

$$\lambda = \frac{300,000}{f}$$

When the frequency is in MEGACYCLES per second, the formula becomes

$$\lambda = \frac{300}{f}$$

The wavelength, λ, in meters may be converted to wavelength in feet on the basis that one meter is very nearly equal to 3.28 ft. (Officially, the meter is equal to 39.37 in.)

Physical Length

The wavelength formulas given in the preceding paragraphs are based on the velocity of radio waves in free space. If these formulas were used to calculate the length of an antenna (for example, a full-wave antenna), it would be found that the antenna resonates at a slightly lower frequency than the desired one. To bring the antenna into resonance at the desired frequency,

the antenna must be shortened. For example, the electrical length corresponding to 50 mc is $\frac{300}{50}$ or 6 m. A physical length of 6 m corresponds to a resonant frequency of $f = \frac{300 \times 0.95}{6} = 47.5$ mc. If the antenna is shortened to $\lambda = \frac{300 \times 0.95}{50} = 5.7$ m, it will resonate at 50 mc. Thus, the length of a practical full-wave antenna is 95% of a theoretical full-wave antenna in free space. There are two reasons to account for the 0.95 factor.

First, the velocity of propagation of radio waves along a metallic conductor is somewhat slower than the propagation through free space. Because $\lambda = v/f$, a reduction in velocity causes an effective reduction in the wavelength; therefore the antenna is made shorter to conform to the reduced wavelength.

Second, a further shortening of the physical length of the antenna is caused by the presence of insulators, supporting wires, reflecting surfaces, and other structures located near the ends of the antenna. The effect of stray capacitance thus added to the antenna is called END EFFECT. If the antenna were made of extremely small wire and isolated perfectly in space, it would have an electrical length corresponding closely to its physical length; that is, a cone-wavelength antenna for 10 m would be 10 m in length. However, such an antenna is impracticable, if not impossible, to construct.

Input Impedance

In a half-wave antanna, the current is maximum at the center and zero at the ends; whereas the voltage is maximum at the ends and minimum at the center. The impedance, $\frac{E}{I}$, therefore varies along the antenna and is minimum at the center and maximum at the ends. Thus, if energy is fed to a half-wave antenna at its center, it is said to be CENTER FED or CURRENT FED; if energy is fed at the ends, it is said to be END FED or VOLTAGE FED. In the case of a resonant half-wave antenna isolated in free space, the impedance (resistive) is approximately 73 ohms at the center and 2500 ohms (allowing for losses) at the ends. The intermediate points have intermediate value of impedance (containing reactance). This subject is treated more fully in Basic Electronics, NavPers 10087-A.

Radiation Resistance

An antenna acts like a resistor that absorbs a certain amount of energy from the source. Disregarding the losses that occur in the antenna, this is the energy that is radiated into space. The value of resistance (when used in place of the antenna) which would dissipate the same power that the antenna dissipates is called the RADIATION RESISTANCE of the particular antenna. The power dissipated in a resistor is equal to I^2R. Likewise, the power dissipated in (radiated form) an antenna is equal to the current (at the feed point) squared times the radiation resistance of the antenna.

The radiation resistance of an antenna depends on the length of the antenna and also to some extent upon its height and proximity to nearby objects. For a half-wave antenna in free space, the radiation resistance is approximately 73 ohms, measured at a current maximum (center of the antenna). For a quarter-wave grounded antenna, the radiation resistance measured at the current maximum is approximately 36.6 ohms. (See Basic Electronics, NavPers 10087-A.)

Wave Polarization

The position of a simple antenna in space determines the polarization of the emitted wave; that is, the direction of the ELECTRIC lines of force determines the polarization of the wave. Thus, an antenna that is vertical with respect to the earth radiates a vertically polarized wave, whereas a horizontal antenna radiates a horizontally polarized wave.

When low-frequency transmission is used, the polarization is not affected to any large degree during transmission to a distant receiving station. If a vertically polarized signal is transmitted, a vertically polarized signal is received. When high-frequency transmission is used, the polarization usually varies, sometimes quite rapidly. Therefore, the polarization of the wave at the receiving station may or may not be the same as the polarization of the wave at the transmitting station.

When the antennas are close to the ground, vertically polarized waves yield a stronger signal close to the earth than do horizontally polarized waves. When the antennas are at least one wavelength above ground, the types of polarization give approximately the same field intensities near the earth. When the antennas are

several wavelengths above the ground, horizontally polarized waves yield a stronger signal close to the earth.

Ground Reflections

The total radiation from an antenna, in effect, is made up of two components. One component leaves the antenna directly; the other is a ground reflection that appears to come from a mirror image of the real antenna, as shown in figure 11-1. The antenna need not be placed at the surface of the earth to produce an image. The image concept holds equally well for antennas above the surface of the earth or for antennas placed in front of large flat sheets of conducting materials.

Figure 11-2 shows current distribution in various real antennas and their images. It will

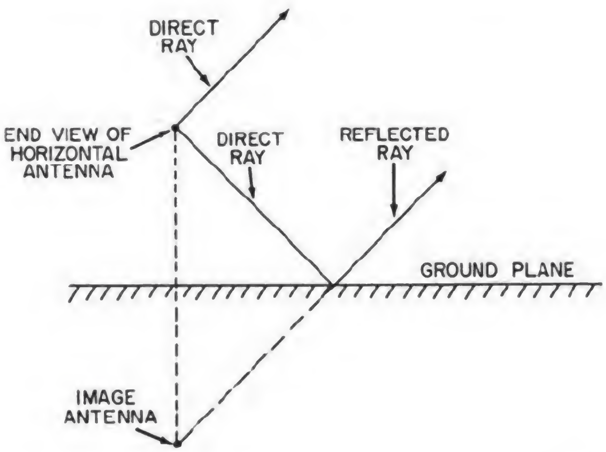

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Figure 11-1. —Direct ray from a horizontal antenna and the reflected ray from its antenna and the reflected ray from its image.

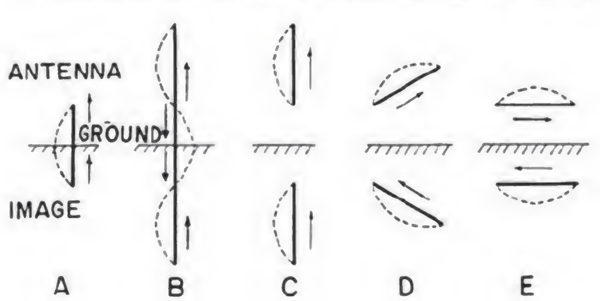

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Figure 11-2.—Current distribution in real and image antennas.

be noted that the currents in the grounded antennas (fig. 11-2A and B) and their images are flowing in the same direction and are therefore in phase. The current distributions in half-wave antennas (and their images) for various positions of the antenna above the surface of the earth are shown in figure 11-2C, D, and E. It may be seen that the currents in the vertical ungrounded antenna and its image are in phase whereas the currents in the horizontal antenna and its image are 180° out of phase. Thus, the effect of ground reflection is different for vertical antennas as compared with horizontal antennas.

The total radiated field in any direction from an antenna and its image is represented by the vector sum of the direct wave and the reflected wave. There are certain directions in which the direct wave from the real antenna and the reflected wave from the image are exactly equal in amplitude but opposite in phase. There are other directions in which the direct and reflected waves are equal in amplitude and in phase. Thus, depending on the direction and location of the point at which the field strength is measured, the resultant field strength may be (1) twice the field strength from the real antenna alone, (2) zero field strength, or (3) some intermediate value.

In figure 11-3, polar diagrams are used to show graphically the result of ground reflection. The graphs are not plots of the radiation patterns, but are simply plots of mutiplying factors (representing the effect of reflection from the ground on the free-space pattern) versus the vertical angle. From the figure, it may be seen that at certain vertical angles the ground reflection factors may increase the free-space pattern by a factor of two or it may reduce it to zero or some intermediate value.

Figure 11-3A shows a plot of the ground-reflection factor for vertical half-wave antennas placed at distances ranging from one quarter-wave to three half-waves above a theoretically perfectly conducting ground. Figure 11-3B shows the plots of the ground-reflection factor for horizontal half-wave antennas for the same distances above ground.

As seen from the graphs, the reinforcement of the radio waves in some directions and their cancellation in other directions cause an antenna system to have a non-uniform vertical field pattern. Thus, where reinforcement occurs, lobes are present; where cancellation occurs, gaps are present. Wave-length and the height of the antenna above ground are the main factors

that determine the angle of elevation of the lobes and gaps in the vertical polar diagrams. If the height of the antenna is larger compared with the wavelength, the first lobe will be at a very low angle. Although these graphs are subject to errors because the earth is not a perfect conductor, on the whole they give satisfactory indication of the effects of ground reflection.

Angle of Radiation

The angle between the horizontal plane and the path of the radiated energy is called the ANGLE OF RADIATION or the ANGLE OF PROPAGATION. If the angle of radiation is less than the CRITICAL ANGLE (the angle between the horizontal plane and the path of the radiated energy beyond which energy is not reflected or refracted by the ionosphere back to the earth), the sky-wave signal will be returned to earth at a certain distance (skip distance) from the antenna. (In some instances the critical angle is taken as the complementary angle of the critical angle shown in figure 11-4.) The smaller the angle of radiation the greater will be the distance to the point at which the wave returns to earth.

Wave Angle

The angle, commonly labeled Φ, between an antenna conductor and the axis of any main lobe is called the WAVE ANGLE (fig. 11-5).

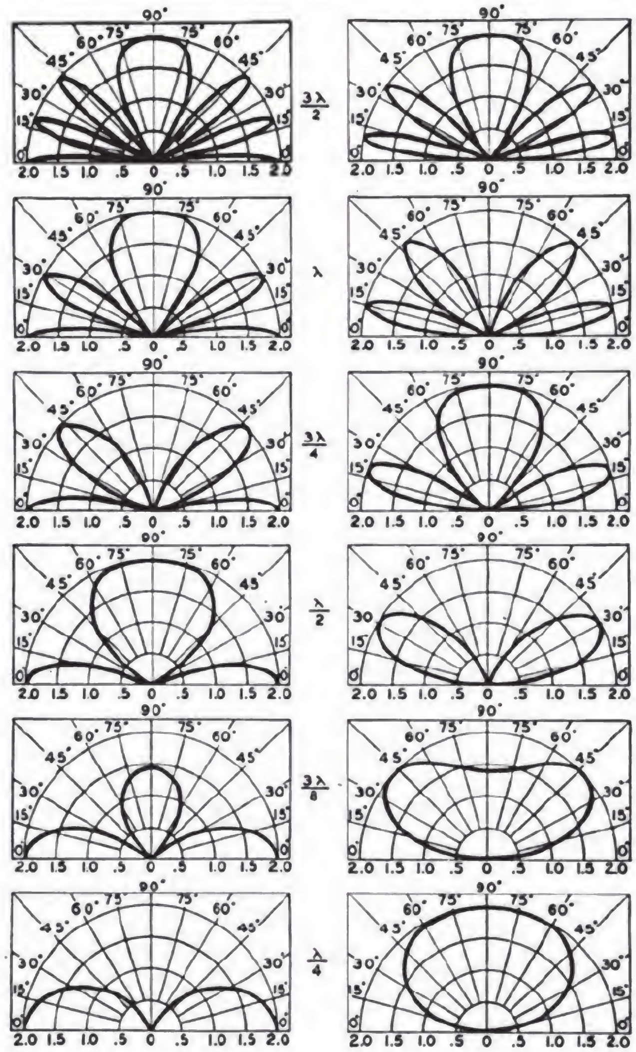
Skip Distance

Skip distance is the distance between the transmitter antenna and the point at which the wave returns from the ionosphere to the earth (fig. 11-4). The skip distance depends on the height and nature of the ionospheric layer, the operating frequency, and the height and type of antenna used. In general, skip distances decrease when the transmitted frequency is decreased or when the angle of radiation is increased.

Antenna Gain

The GAIN of an antenna is a rating by which one receiving or transmitting antenna may be compared with another antenna. For receiving antennas, it is the ratio of the signal power produced at the receiver input by the antenna being considered to the signal produced by the comparison antenna (the ratio is usually expressed in decibels).

The gain of one transmitting antenna over another transmitting antenna can be determined by obtaining the absolute field strengths of both



A
VERTICAL HALF-WAVE ANTENNA

B
HORIZONTAL HALF-WAVE ANTENNA

HEIGHT OF CENTER OF ANTENNAS ABOVE A PERFECT GROUND IS INDICATED IN WAVELENGTHS

25.199

Figure 11-3.—Plot of the ground reflection factor for different antenna heights as a function of the vertical angle.

antennas at a particular point. Although the gain of an antenna varies with the direction of the radiated energy, gain is usually considered in the direction of maximum field strength.

When comparing the gain of one antenna with that of another, the power fed to both must be the same, and both must be orientated in the same direction.

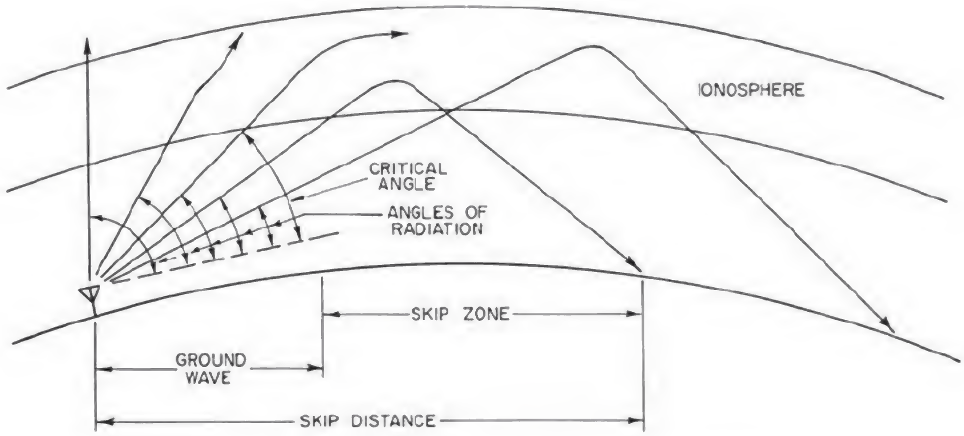


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Figure 11-4.—Paths of sky-wave transmission.

As an example, assume that the gain of antenna A1 is to be compared with that of antenna A2. If antenna A1 has a field intensity (in microvolts/meter) 3 times that of A2, the db gain of A1 over A2 is:

$$\text{db gain of A1 over A2} = 20 \log_{10} \frac{3}{1} = 9.5$$

(approximately).

(Decibels are discussed in Basic Electronics, NavPers 10087-A.)

The gain of an antenna or antenna system, may be given in terms of a standard reference field strength instead of in terms of the field strength produced by a given antenna. As an example, assume that the reference field strength is 186μv/m at a distance of 1 mile for an input of 1 kw. (This value is sometimes used in actual tests.) With the antenna under test, assume that the field strength is 558μv/m at a distance of 1 mile for an input of 1 kw. The gain of the antenna under test over the reference field strength is:

$$\text{db gain of antenna} = 20 \log_{10} \frac{558}{186} = 9.5$$

(approximately).

If the input power of the antenna under test is not 1 kw, then the refernce field strength

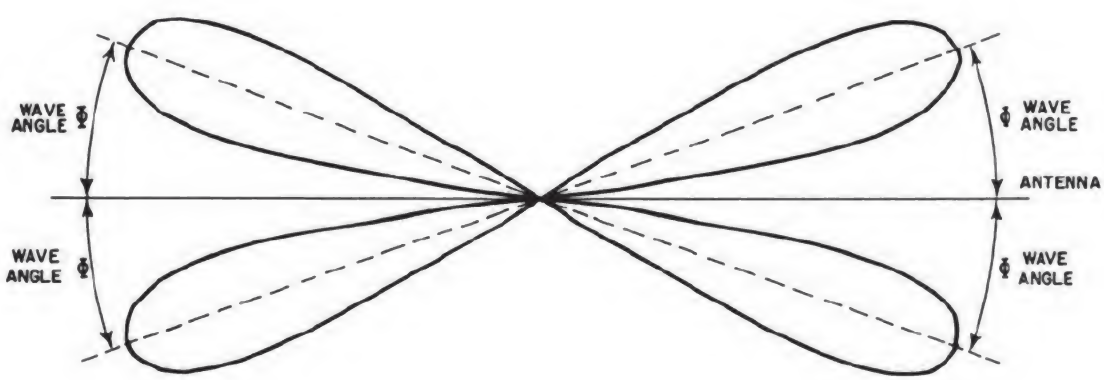

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Figure 11-5.—Antenna wave angle.

will not be 186 μv/m but will be the square root of the power fed to the antenna under test times 186 μv/m. For example, if the input power of the antenna under test is 2 kw, the reference field will be $\sqrt{\frac{2}{1}}$ x 186 = 263 μv/m. If the field strength of the antenna under test is 790 μ v/m, the gain of the antenna will be 20 log $\frac{790}{263}$= 9.5 db.

BASIC ANTENNAS

Half-Wave Antennas

The most basic antenna unit is the half-wave antenna (dipole). Half-wave antennas are generally referred to as Hertz antennas, and are also known by many other names that describe or identify the type of feed (coupling) used. Some examples are doublets, delta-matched, and Zepp antennas. (See figure 11-6.)

Half-wave antennas have wide use in the Navy, both for transmitting and receiving. The different types of feed have been developed from the problems of power dissipation associated with the considerations of transmitting. Since these considerations are generally of little concern for receiving antennas, many of the variations offer little advantage over the basic design.

The directivity of a half-wave antenna is somewhat affected by polarization. The radiation field, or for purposes of reception, the area from which signals may be received, may be likened to a doughnut on a stick. (See figure 11-7.) In the case of a vertical half-wave antenna, the field exists fairly equally in all directions in a plane perpendicular to the axis of the antenna.

The presence of ground modifies the free space directivity pattern, due to the reflection and absorption of the radiated wave from the antenna. Reflection takes place because the electromagnetic wave leaves the antenna at such angles that some of the radiation strikes the earth's surface. At any point in space surrounding the antenna, the resultant radiation will be composed of two components—that reflected from the ground, and that arriving directly from the antenna. The reflected component will tend to reinforce or to cancel the direct component depending on the phase relationship of the two components. The amount of reinforcement or cancellation is dependent on the amplitude of the reflected wave. The phase relationship is a function of the height of the antenna above the ground, and to a certain extent by the conductivity of the ground. The amplitude of the reflected component is largely a function of the conductivity of the ground. Therefore, the presence of ground distorts the free space directivity pattern, the amount of distortion being dependent on the height of the antenna above ground and the conductivity of the ground.

A horizontal half-wave antenna in free space will also have a doughnut-shaped field surrounding it. When in the presence of the ground, this doughnut-shaped field is also affected by the conductance of the ground and by the height of the antenna from ground.

End-Fed Half-Wave Antenna

A resonant section of transmission line used to end-feed a half-wave antenna is shown in figure 11-8.

The impedance of a half-wave antenna is approximately 2500 ohms at the ends. At any odd number of quarter wavelengths along the resonant transmission line, the high impedance of the antenna feed point will appear as a low impedance and may be matched by the low impedance of the series-tuned circuit composed of C1, C2, and L1, as shown in figure 11-8A.

When the length of the feeder system is an even number of quarter wavelengths, parallel tuning, as shown in figure 11-8B, is used. Because a half-wavelength section of resonant transmission line acts like a 1-to-1 impedance-matching transformer, the high impedance of the antenna feed point is matched by the high impedance of the parallel-tuned circuit composed of C1L1.

The antenna length must be correct to within 10 percent for the frequency used because no amount of feeder tuning can bring about a balance of currents in the feeder conductors for an antenna that is too short or too long. When the antenna is too long or too short, feeder unbalance and resultant feeder radiation will occur. Feeder unbalance is a condition in which the currents in the two conductors are not equal and 180° out of phase. When the antenna length is correct, the currents in the two conductors of the feeder are essentially equal in amplitude and 180° out of phase, as shown in figure 11-9A. When the antenna is too long (fig. 11-B), the antenna current goes through a reversal, and the current in the left-hand feeder is advanced with respect to the current in the right-hand feeder. The feeder currents are not exactly 180° out of phase; consequently there will be some radiation from the transmission line. When the antenna is too

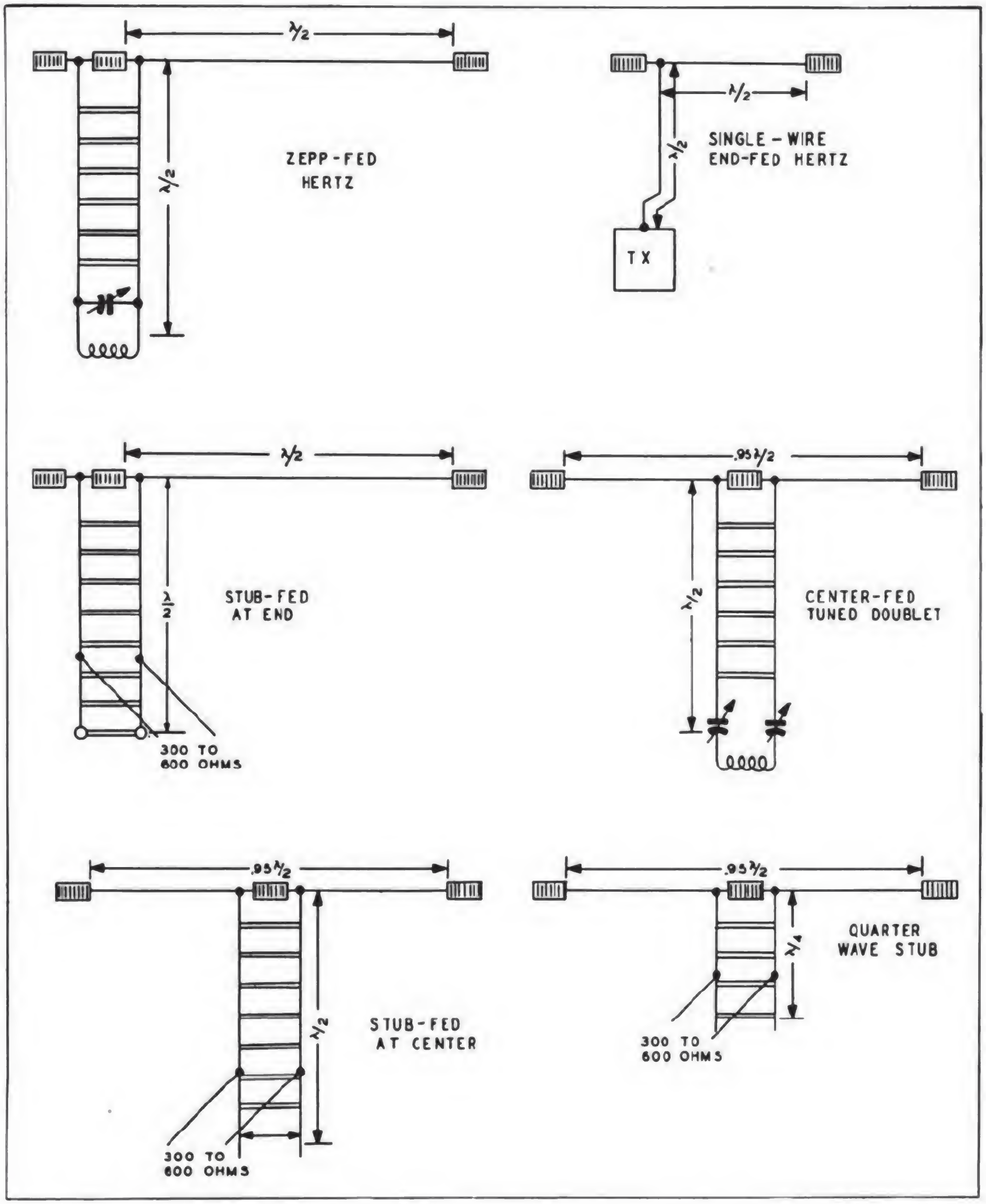

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Figure 11-6. —Examples of basic half-wave antennas.

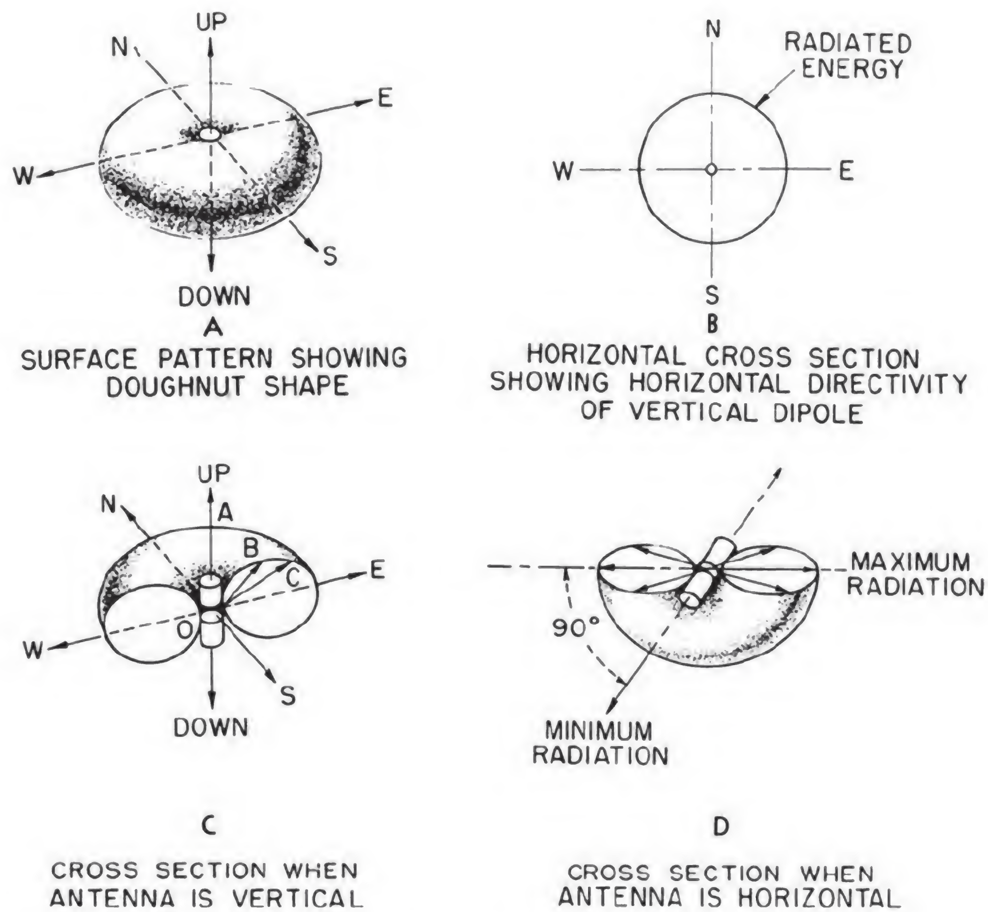

Figure 11-7.—Radiation pattern of a dipole.

short (fig. 11-9C), unbalance again occurs. The current in the left-hand feeder is retarded with respect to the right-hand feeder, and radiation from the feeder again occurs.

This type of antenna may be checked for correct operation in the following manner:

1. The antenna is lowered, the feeders disconnected from the antenna, and then again raised to their original position.
2. The transmitter is turned on, and the feeders tuned to resonance.
3. The transmitter is turned off, and the feeders reconnected to the antenna without disturbing the feeder tuners.
4. The transmitter is turned on again. If the antenna length is incorrect, the system will not resonate. For example, in figure 11-8A, if the antenna is too short it will present capacitance to the tuning circuit L1, C1, and C2. The added capacitance acts in series with L1, C1, and C2, thereby reducing the total effective capacitance in the circuit. To resonate the circuit, C1 and C2 are increased to compensate for the antenna capacitive component. If the antenna is too short, it will present capacitance to the output end of the half-wave feeder. This action will appear to be inductive at the input end of the feeder because of phase shift through the half-wave line. The inductive effect acts in parallel with the feeder tuning circuit inductor, L1, thereby lowering the total inductance of the circuit. To compensate for the reduction, the capacitance of the tuning capacitor, C1, is increased in order to bring the system into resonance.

If the capacitance must be decreased to reach resonance in both figures, the antenna is too long. The feeders do not need retuning when the antenna

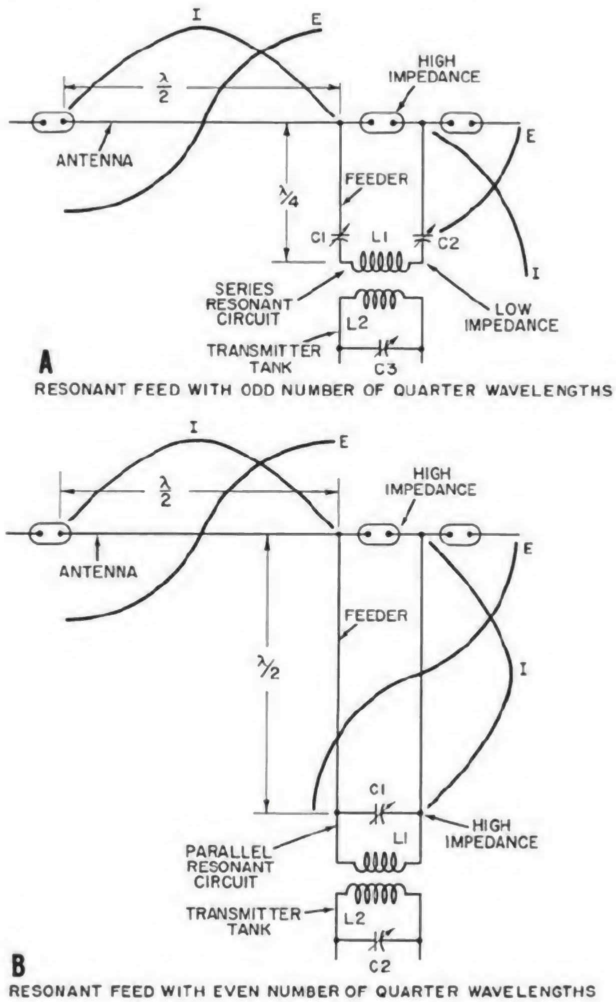

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Figure 11-8.—Methods of feeding a half-wave antenna by a resonant line.

length is correct for the given operating frequency.

The methods of transmitter coupling shown in figure 11-8 may be modified. For example, link-coupling may be used. When this type of coupling is used, the number of turns needed may be approximately 2 or 3 at 20 mc, or 10 or 12 at 3 mc. At the lower frequencies, the capacitors would have a maximum capacitance of at least 250 to 350 $\mu\mu$ f. Capacitors having a lower value are used as the operating frequency is increased. Higher wattage transmitters require wider spacing between the stator and rotor plates of the capacitors.

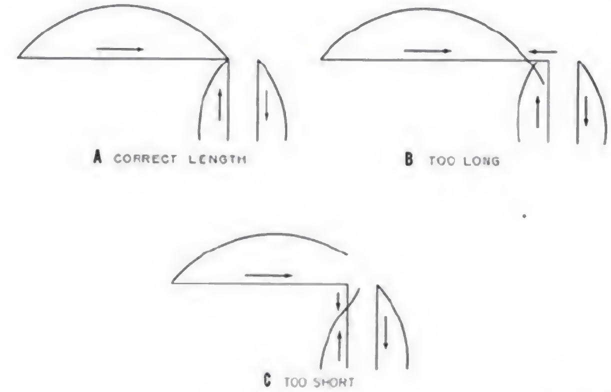

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Figure 11-9.—Effects of variations in antenna length

In some instances, the feeders are of such length that the antenna will not draw power even when the $\frac{L}{C}$ ration of the tuned circuit is altered. Adding or subtracting approximately one-eighth wavelength of transmission line or adding loading coils in series with each feeder may cause the antenna to draw power. As an alternative, the feeders may be tapped down toward the center of a coil in parallel-tuned resonant circuit as shown in figure 11-10.

Before World War II, the end-fed half-wave (Zepp) antenna was widely used in communications systems. Its popularity arose from the fact that it is automatically matched to its feeder at the feed point for all even-order harmonics.

One disadvantage is that it is very difficult to eliminate all radiation from its feeders, therefore the over-all efficiency of the antenna system is lowered. For radiating a relatively broad band of frequencies that are not related harmonically, the feed line will not be matched to the transmitting source; hence reduced power output will result. Futhermore, feeder current unbalance will result in increased radiation loss from the feeder. Thus, this type of antenna

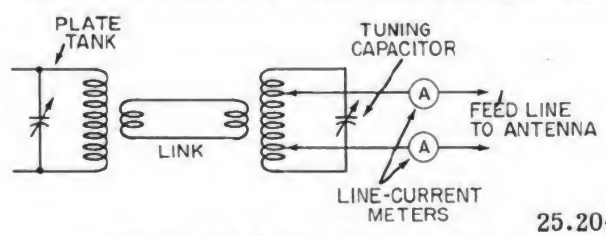

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Figure 11-10.—Coupling method.

system is useful only for radiating the resonant frequency and a very narrow band on either side of the carrier.

Center-Fed Half-Wave Antenna

A tuned transmission line may be used to feed a half-wave antenna at its center. When this arrangement is used, it is called a TUNED DOUBLET (also called a center-fed Zepp or current-fed Zepp). The radiation resistance of the antenna is lowest at the point where the feeders are connected. This condition is exactly opposite to the condition existing when an end-fed half-wave antenna is used. Therefore, parallel tuning is used when the resonant feed line is an odd number of quarter-wavelengths long, and series tuning is used when the resonant feed line is an even number of quarter-wavelengths long. The two conditions are shown in figure 11-11.

If the electrical lengths of the feeders are equal, incorrect antenna length or operating frequency will not unbalance the feeder currents as it does in the case of the end-fed half-wave antenna. Instead, the standing waves on the feeders move symmetrically along both feeders and complete balance is maintained. Thus, it is possible to use the tuned doublet over a comparatively wide range of frequencies without undue losses or radiation from the feeders. Furthermore, the inherent unbalance of the feeders found in the end-fed half-wave antenna is not present in the tuned doublet because the two feeder wires are equally loaded.

The tuned doublet operates as a current-fed system on its fundamental frequency and as a voltage-fed system on even harmonics. When this antenna is operated on its second harmonic, it is known as a FRANKLIN COLINEAR ARRAY.

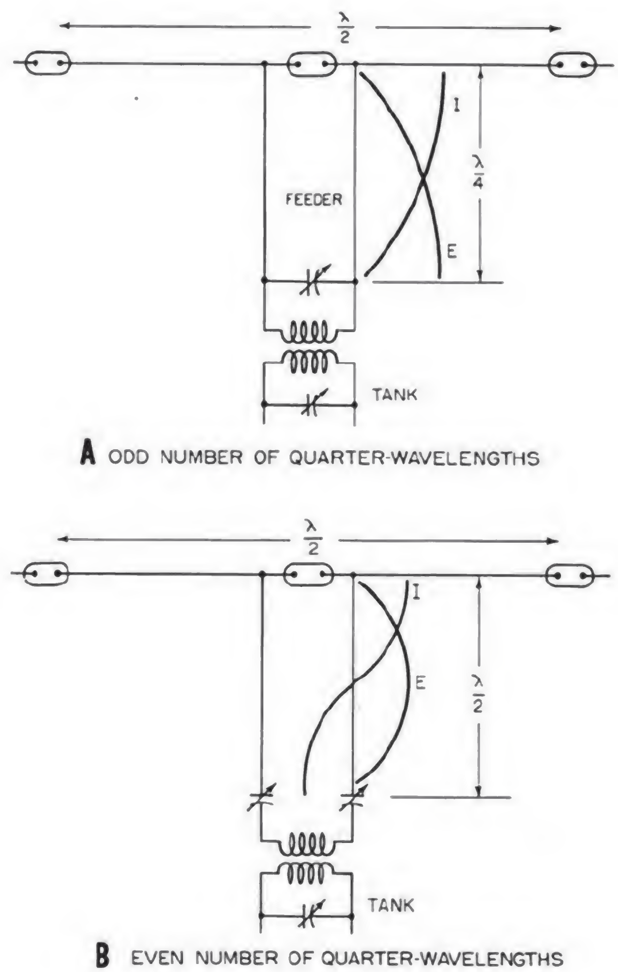

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Figure 11-11.—Center-fed half-wave antenna (tuned doublet).

QUARTER-WAVE ANTENNAS

The usual MARCONI antenna is a grounded vertical quarter-wave antenna. The vertical portion acts like one-half of a half-wave antenna, and the ground or earth acts like a mirror image to supply the missing quarter-wave section. Figure 11-12 illustrates the standing waves of current and voltage as they exist on a MARCONI antenna. The current maximum is at the base (feed point) and therefore the antenna is current-fed—that is, fed at a point of low impedance. For a properly tuned antenna, the radiation resistance is approximately 36 ohms.

A vertical grounded antenna must be an odd number of quarter-wavelengths long if the current maximum (low impedance) is to occur at the base. For example, if the antenna is less than a quarter-wavelength long, it will be capacitive at the base, and a coil must be added in series at this point to make it resonant. If it is more convenient, the same result can be accomplished by effectively adding a capacitive effect (top loading) at the top of the antenna. If the antenna is slightly more than a quarter-wavelength long, the input at the base will be inductive, requiring the addition

of a series capacitor near the feed point to bring the antenna into resonance.

The length, L, in feet of a $\frac{\lambda}{4}$ Marconi antenna is computed by means of the formula,

$$L = \frac{234}{f}$$

where f is in megacycles. In this case, L, is the over-all length from the top of the antenna to the point where it connects to the ground or counterpoise.

The radiation resistance (and efficiency) of the Marconi antenna decreases as the physical length of the antenna is reduced. A reduction in physical length also affects the match to the transmission line.

The total power, P_t, dissipated in, and radiated from, a Marconi antenna is computed from the formula,

$$P_t = I^2 (R_r + R_g)$$

where I is the antenna current measured at the base of the antenna, R_r is the radiation resistance, and R_g is the ground resistance. The radiated (useful) power is equal to the difference between the total power consumed and the power dissipated (lost) in the ground resistance. Thus, the radiated power, P_r, is

$$P_r = P_t - I^2 R_g$$

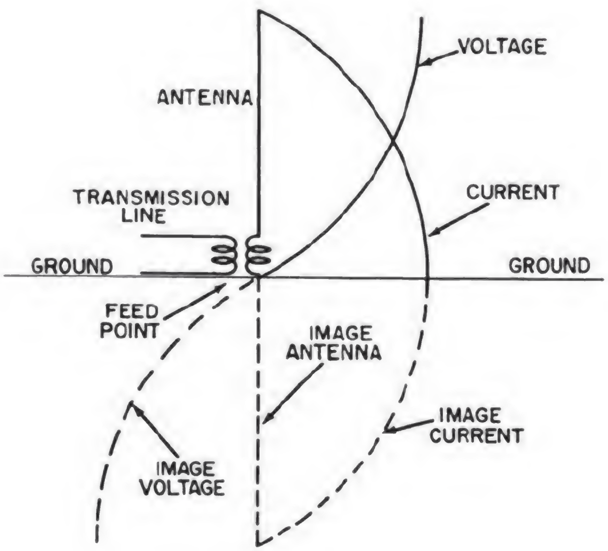

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Figure 11-12.—Marconi antenna and waveforms of current and voltage.

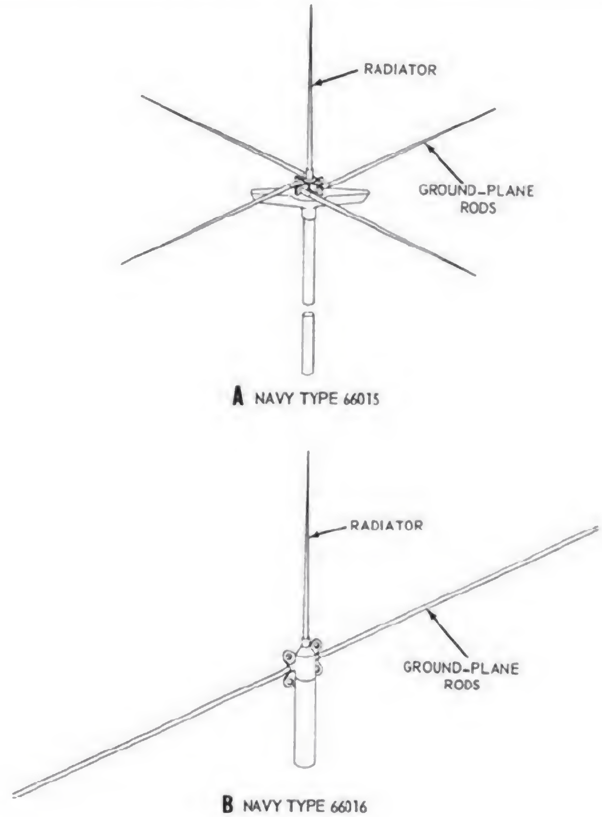

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Figure 11-13.—Navy-type ground-plane antennas.

Two types of $\frac{\lambda}{4}$ antennas used by the Navy for communication in a portion (60 to 80 mc) of the v-h-f range are the ground plane antennas shown in figure 11-13. Navy type 66015 is shown in part A. Four horizontal rods are used for the ground plane and a vertical rod of the desired length is used as a $\frac{\lambda}{4}$ radiator.

The Navy type 66016 (fig. 11-13B) is similar to the Navy type 66015, except that only two horizontal rods are used for a ground plane. This antenna is designed for submarine use.

LONG-WIRE ANTENNAS

Long-wire, or multiple-wavelength, antennas have directional characteristics that may be used to advantage when a directional pattern is desired. Figure 11-14 illustrates how the major lobes make smaller wave angles with their respective antennas as the length of the antennas are increased. For the $\lambda/2$ antenna, the wave angle Φ, is 90°; for the λ antenna, it is 54°; for the $\frac{3}{2}\lambda$ antenna, it is 42°; for the 2λ antenna, it is 36°; and for the 5λ antenna, it is 22.5°. The graph gives the radiation angle of the main lobes with respect to the antenna axis for various lengths of the antenna.

Tilting the antenna from the horizontal, position (1) figure 11-15, to position (2) increases the transmission distance and low angle radiation from A to B and decreases them from C to D. Note that the direction of increased radiation is the same general direction as that of the downward tilt of the antenna.

Wave (Beverage) Antenna

The wave antenna is a horizontal long-wire antenna one or more wavelengths long and terminated at one end in its characteristic impedance (approximately 500 ohms). Generally, by using poles, this type of antenna is suspended about 10 to 20 feet from the ground and is terminated to ground in its characteristic impedance at the end nearest the transmitter (when the antenna is used for receiving). The antenna may be considered a one-wire transmission line with a ground return.

The schematic diagram of a wave antenna is illustrated in figure 11-16. Because of its termination, the antenna is nonresonant and may be used for the reception of several different frequencies without too much variation in directivity. Because the ground losses are high, this type of antenna is not very efficient for transmitting, but is often used for receiving.

The vertical transmitting antenna radiates a vertically polarized wavefront. As the wavefront travels toward the receiving antenna, it is tilted forward because of the absorption of the earth and the resultant decrease in propagation velocity. When the wavefront arrives at the receiving antenna, the E lines are no longer vertical. Instead, they have both a vertical and a horizontal component. The horizontal component is effective in inducing a voltage in the receiving antenna. Therefore, the more the wavefront is tilted, the greater the horizontal component and the greater the voltage induced in the antenna.

The amount of tilt depends on the wavelength and the type of earth over which the wave passes. At standard broadcast frequencies, the tilt may be from 6° to 12°; at higher frequencies the tilt may be 20° or more. At the lower frequencies and over good ground (salt marshes or salt water) the tilt is scarcely perceptible. At the higher frequencies and over poor ground the tilt is maximum.

The effects of tilt are good in that the wave tends to follow closely the earth's contours; they are bad in that the greater the tilt the more the over-all signal strength is reduced. However, the horizontal component is increased with an increase in tilt angle, and this is the component that is effective in inducing signal voltages in the antenna.

V Antenna

A V antenna is a bidirectional antenna widely used in military and commercial communication applications. It is made up of two long-wire antennas arranged in the form of the letter V and fed 180° out of phase at the apex AC, as shown in figure 11-17. If the length of the LONG-WIRE ANTENNA is increased, more power is concentrated near the axis of the wire. Because the V antenna is a combination of two long-wire antennas, the same reasoning may be applied to the V antenna as is applied to long-wire antennas.

The lobes on leg AB are labeled 1, 2, 3, and 4; the lobes on leg CD are labeled 5, 6, 7, and 8. When the proper angle, Φ, between AB and CD is chosen, lobes 1, 8, 3, and 6 combine to produce the resultant pattern. This combination of two major lobes from each leg results in the formation of two stronger lobes that lie along the line that bisects angle Φ. Lobes 2, 4, 5, and 7 tend to cancel; this is also true of the minor lobes.

The graph in the figure indicates the relationship of the apex angle in degrees and the leg lengths in wavelengths for maximum gain. the graph also shows the gain of V antennas of various leg lengths over a half-wave antenna at the same height above ground.

From the graph it may be seen that the apex angle decreases with an increase in leg length.

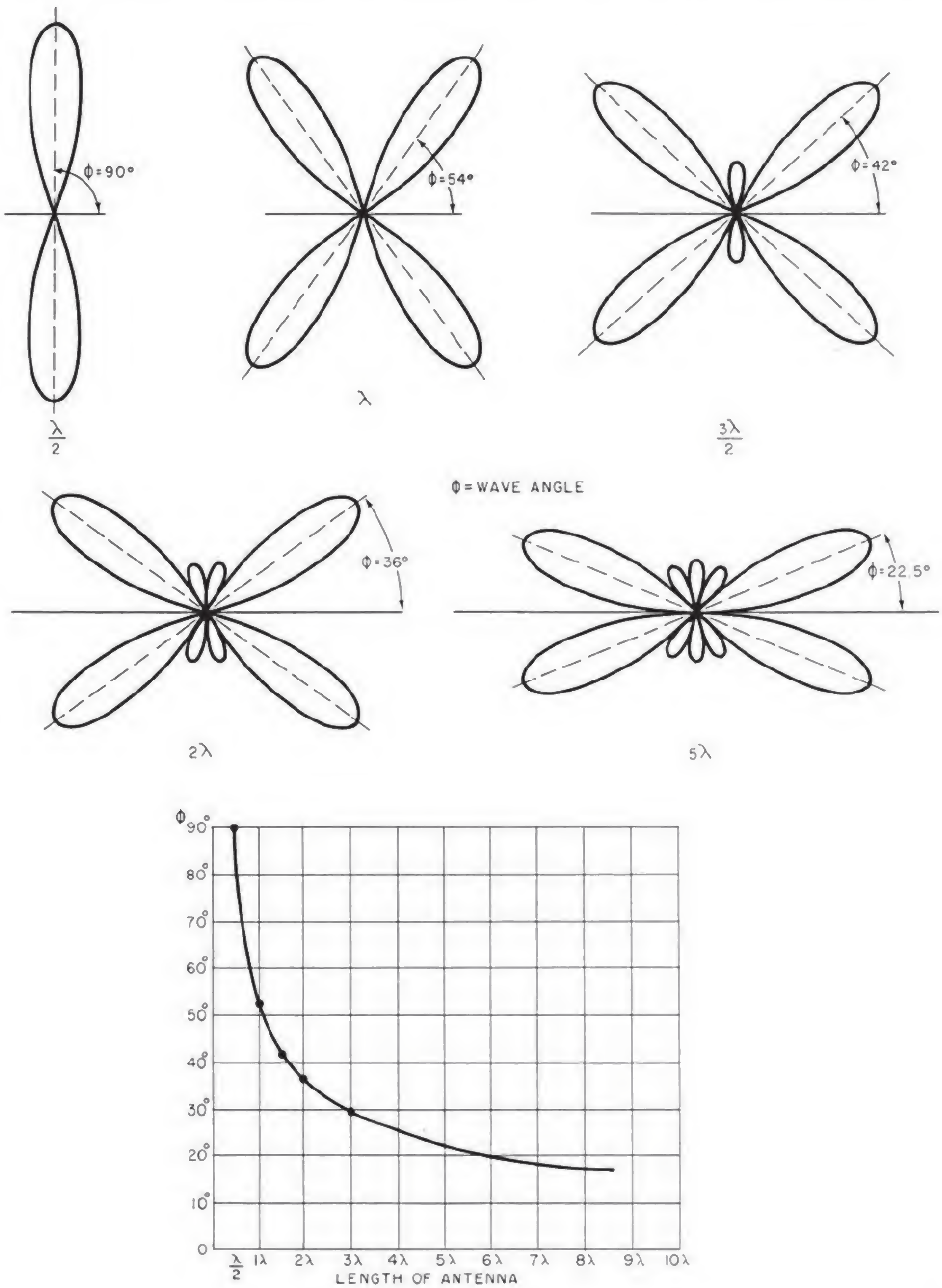

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Figure 11-14.—Free-space radiation patterns of long-wire antennas.

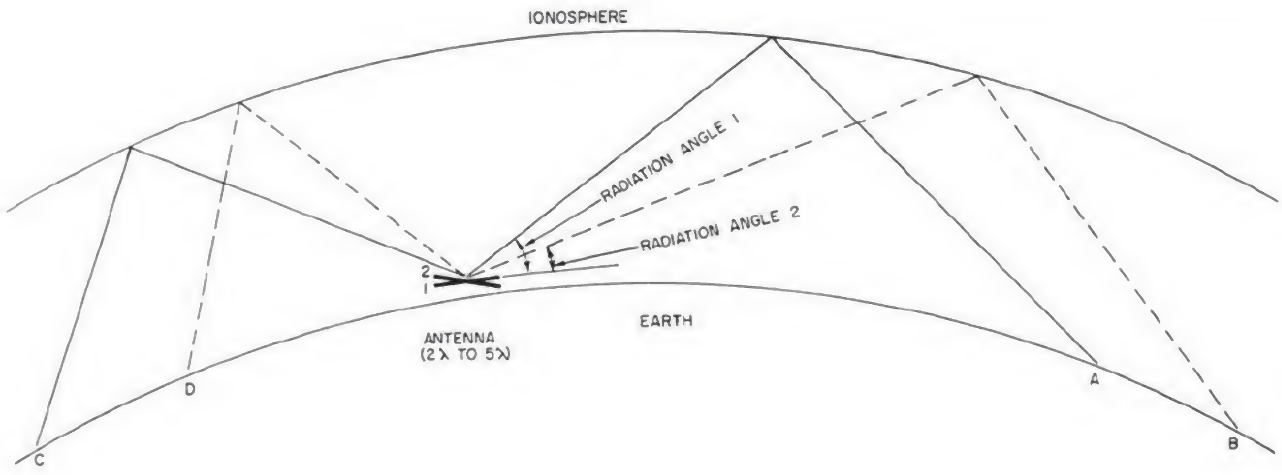

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Figure 11-15. —Effect of antenna tilt.

The wave angle for an antenna one-half wave above ground also decreases with an increase in L.

If the legs of a V antenna are six or more wavelengths long, there is only a slight change in the apex angle required as the legs are lengthened still more. However, because the beam is narrower, orientation becomes increasingly critical. An error of a few degrees in laying out the antenna may result in a considerable loss of signal strength at the receiving station. Extreme care must therefore be used in laying out a high-gain V antenna. If the exact great-circle bearing of the receiving station is not known, or if precision surveying equipment is not available, better results can often be obtained by shortening the antenna to produce a wider radiation pattern.

The proper length in feet of each leg of a V antenna is found by use of the empirical formula,

$$L = \frac{492\ (N-0.05)}{f}$$

where N is the number of half wavelengths in each leg, and f is the frequency in megacycles.

For example, the length of each leg of a V antenna if N = 1 and f = 100 is

$$L = \frac{492\ (1-0.05)}{100} = 4.66 \text{ ft}$$

The V antenna may be tilted downward to increase the low-angle radiation from the low end. On a sloping site, the plane of the V antenna should be made parallel with the ground with the open end pointing down the slope.

The V antenna can be made to develop more gain by placing a second V, one-half wavelength above the first. The planes containing the antennas are parallel. This system is called STACKING. The second antenna is fed from the first through a line that is transposed so that the corresponding legs of the two V antennas are in phase. Likewise, a broadside arrangement, forming a W, may be used to increase the gain.

The V antenna can be made to develop a unidirectional pattern in the direction of the open end of the V by terminating the free end of each leg in the proper resistance (between 400 and 800 ohms) to ground. The terminating resistors may be connected to a counterpoise. In any case, there are practical difficulties in properly terminating a V antenna. The resistors should be of the noninductive type and should be capable of dissipating approximately one-half of the power fed to the antenna. The exact value of the terminating resistance is determined by experiment. The value that gives the lowest standing-wave ratio is chosen.

Another method of making a V antenna unidirectional is to place a second V antenna one-quarter wavelength behind the first, forming, in effect, one V within another. The two antennas are fed 90° out of phase.

The V antenna may be fed by means of 600-ohm resonant line attached to the apex of the V. When a nonresonant line is used, a match may be effected by means of a quarter-wave matching stub. Methods of matching transmission lines to antennas are included later in the chapter.

Half-Rhombic Antenna

The half-rhombic antenna is a special form of the long-wire antenna. It is sometimes called the inverted V or tilted-wire antenna. A half-rhombic antenna designed for unidirectional radiation is shown in figure 11-18. The maximum field intensity is radiated in the direction of the terminating resistor. For reception, maximum signal strength is produced at the receiver when r-f energy arrives by way of the terminated end of the antenna.

In order that lobes 1 and 2 may properly combine in the desired direction of propagation, the distance, AC, is approximately a half-wavelength less than distance ABC. This arrangement causes the fields radiated at lobes 1 and 2 to be additive in the direction of propagation. The fields radiated at lobes 3 and 4 cancel.

For efficient transmission, the tilt angle, θ, is equal to 90° minus the wave angle, Φ.

For example, let it be assumed that each leg of a half-rhombic antenna is 3 wavelengths long at the operating frequency. Because the wave angle is essentially the same as that of a long-wire antenna 3 wavelengths long, the wave angle may be determined from the graph in figure 11-14. From the graph, the angle is about 30°. The tilt angle, θ, is

$$\theta = 90 - 30 = 60°$$

The total apex angle is therefore 120°.

Some idea of the dimensions of a half-rhombic antenna for operation at about 4 mc may be obtained from the following considerations. First of all, assume that each leg is to be 3 wavelengths long, as was the case in the preceding paragraph. Neglecting the propagation factor, the wavelength, λ, in meters is approximately

$$\lambda = \frac{300}{f} = \frac{300}{4} = 75$$

In feet it is $\lambda = 75 \times 3.28 = 246$. The length, L, of one leg is therefore $L = 246 \times 3 = 738$ ft. The groundline projection is computed by trigonometry as $L \sin\theta = 738 \times 0.866 = 639$ ft = groundline projection. Therefore the total distance along the ground from the input to the antenna to the terminating resistor is approximately 2 x 639, or 1278 ft.

The altitude of point B may also be computed by trigonometry as

$L \cos\theta = 738 \times 0.5 = 369$ ft = height to point B.

Full-Rhombic Antenna

The rhombic, or diamond, antenna is another form of long-wire antenna. Although the half-rhombic has certain advantages over some

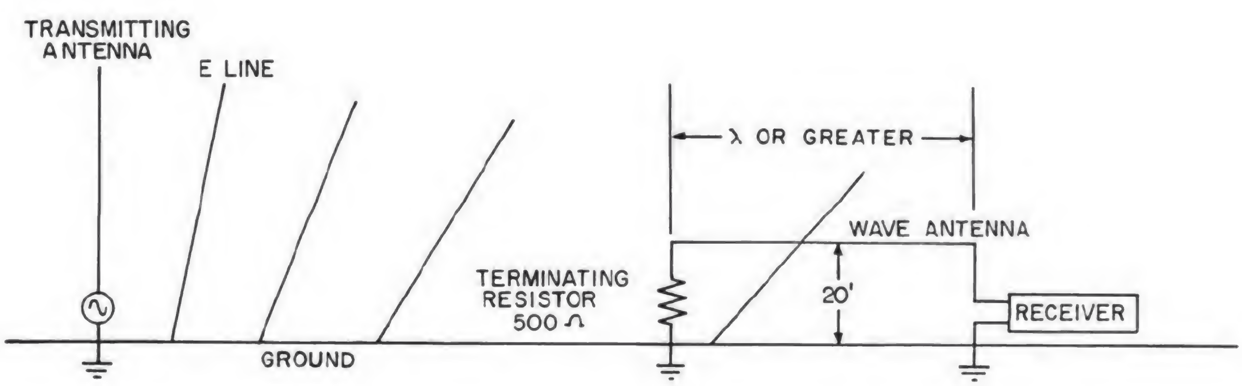

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Figure 11-16.—Wave or beverage antenna.

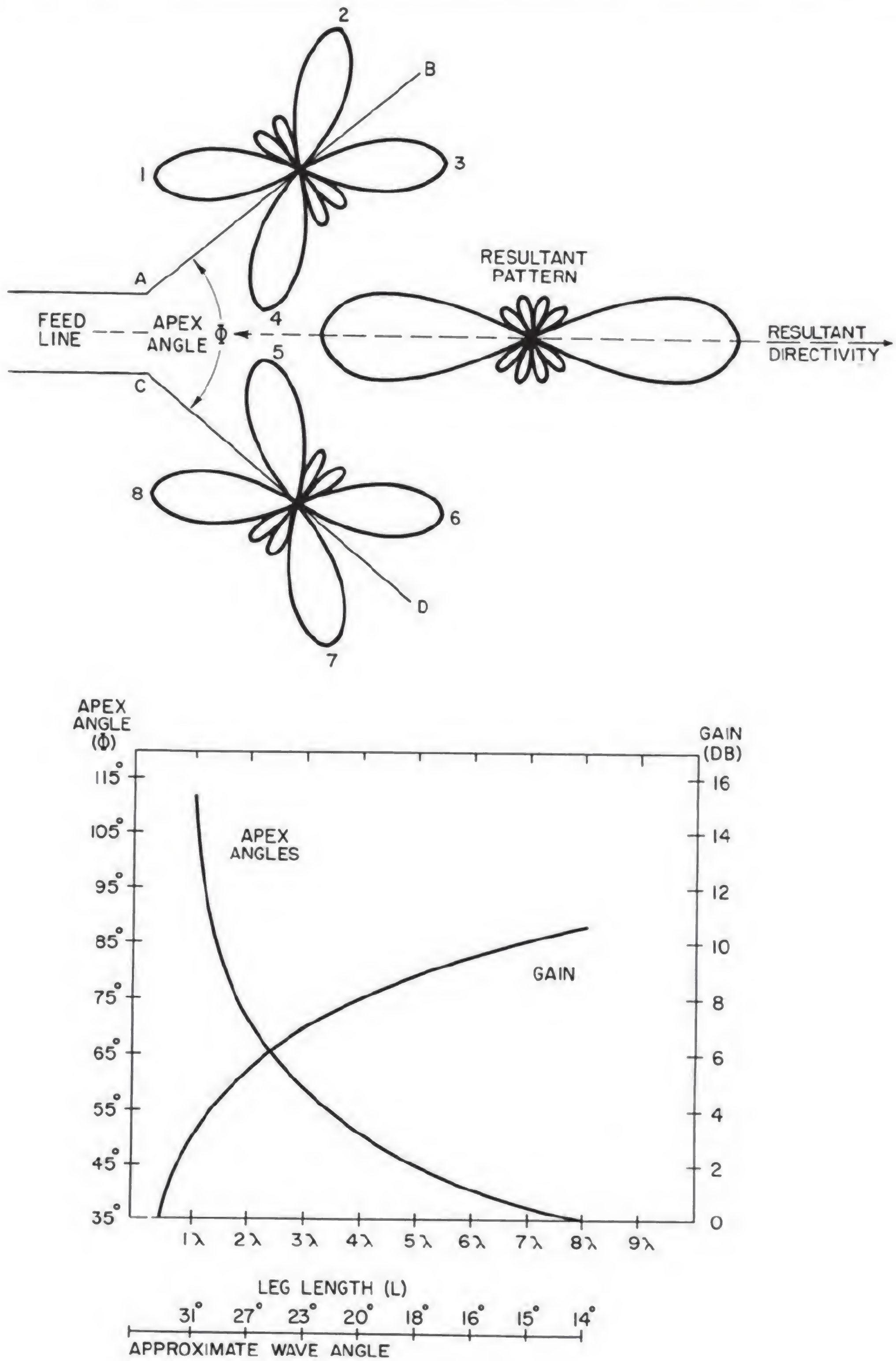

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Figure 11-17.—V antenna and graph of apex angle versus for λ maximum gain.

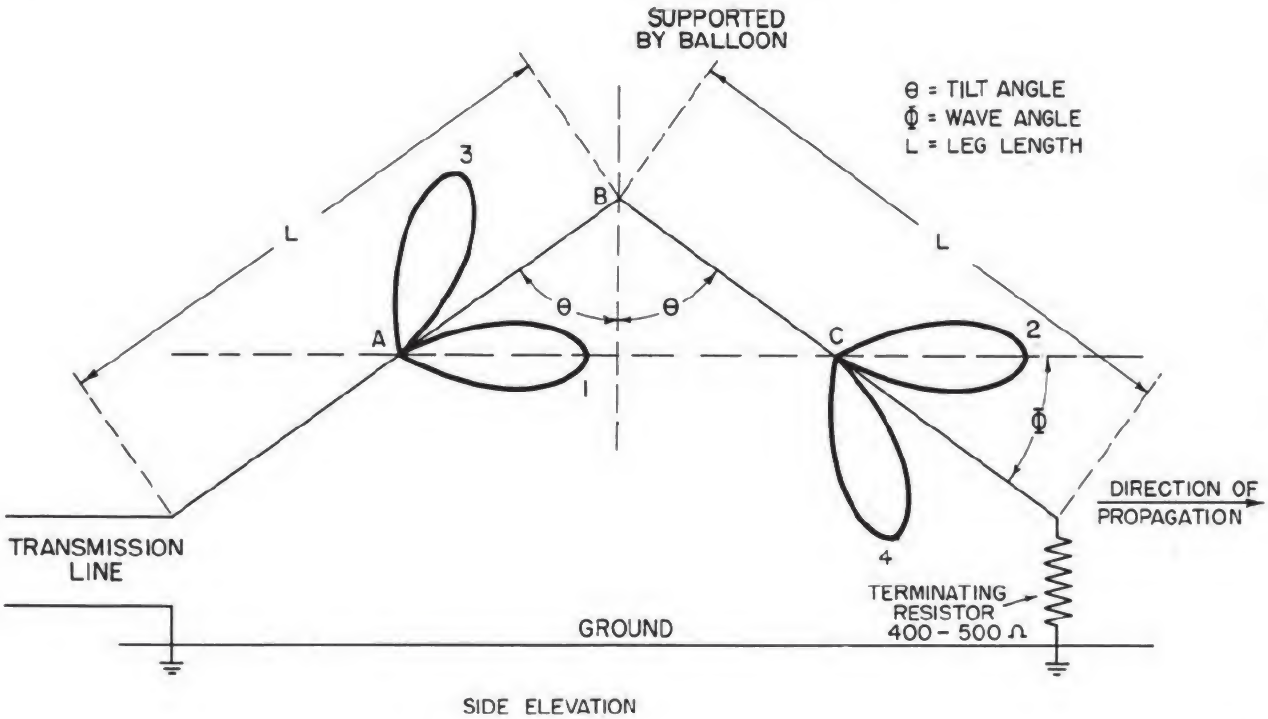

Figure 11-18.—Half-rhombic antenna.

of the other long-wire antennas, it also has certain major disadvantages, such as difficulty in construction and termination. The full-rhombic is one of the better antennas (where adequate space is available for its erection) for obtaining maximum gain in the desired direction. For reception, it provides a good signal-to-noise ratio; and, for transmission, it provides a relatively low angle of radiation (of the order of from 0° to 20°). The full-rhombic antenna is widely used for both transmission and reception at NAVY ANTENNA FARMS; that is, selected localities where large numbers of antennas are installed.

The full-rhombic antenna may be considered as two half-rhombics in a horizontal plane with one end connected to a common terminating resistor and the other to a balanced receiver or transmitter through a suitable transmission line. A schematic diagram of a full-rhombic antenna designed for maximum directivity is shown in figure 11-19. A picture of a receiving rhombic is shown in figure 11-20.

The terminating resistance is at the end of the antenna toward the distant receiver in the case of a transmitting antenna, and at the end of the antenna toward the distant transmitter in the case of a receiving antenna. The input impedance for this type of antenna is essentially constant over a wide range of frequencies.

The gain of this type of antenna depends on the dimensions of the antenna with respect to the wavelength of the operating frequency. The gain of a rhombic antenna is approximately 20 times that of a half-wave dipole when each leg is 2 wavelengths long. When each leg is 4 to 5 wavelengths long, the gain is approximately 40 times that of a dipole. Radiation is maximum in the direction of the terminating resistor and is greatly reduced in all other directions.

In order that lobes 1 and 2 may properly combine along the major axis, the distance, AC, is approximately a half wavelength less than distance ABC. This arrangement is similar to that of the half-rhombic antenna. The fields radiated at lobes 1 and 2 thus become additive in the direction of propagation. The same is true of the fields radiated at lobes 3 and 4. The fields radiated at lobes 5 and 7 cancel. The fields radiated at lobes 6 and 8 also cancel.

The tilt angle, θ, is 90° minus the wave angle, Φ, if maximum energy is to be radiated along the major axis.

For maximum gain in the desired direction, the proper relationship between the tilt angle (θ), the length (L) of each leg, and the height (H) must be maintained. The following formulas are used to obtain these values:

$$\theta = 90 - \Phi$$

$$L = 90 \frac{\lambda}{2 \sin^2 \Phi}$$

where λ is the wavelength of the transmitted signal (when $\lambda = 1$, L is in wavelength) and

$$H = \frac{\lambda}{4 \sin \Phi}$$

The wave angle, Φ, becomes smaller as the leg length becomes longer in terms of wavelengths, as is indicated in figure 11-14. The net effect of increasing the leg length, or of increasing the frequency, is to increase the distance of coverage, as indicated (roughly) in figure 11-21.

As an illustration of the interrelation of Φ, L, and H, assume that a 10-mc communication

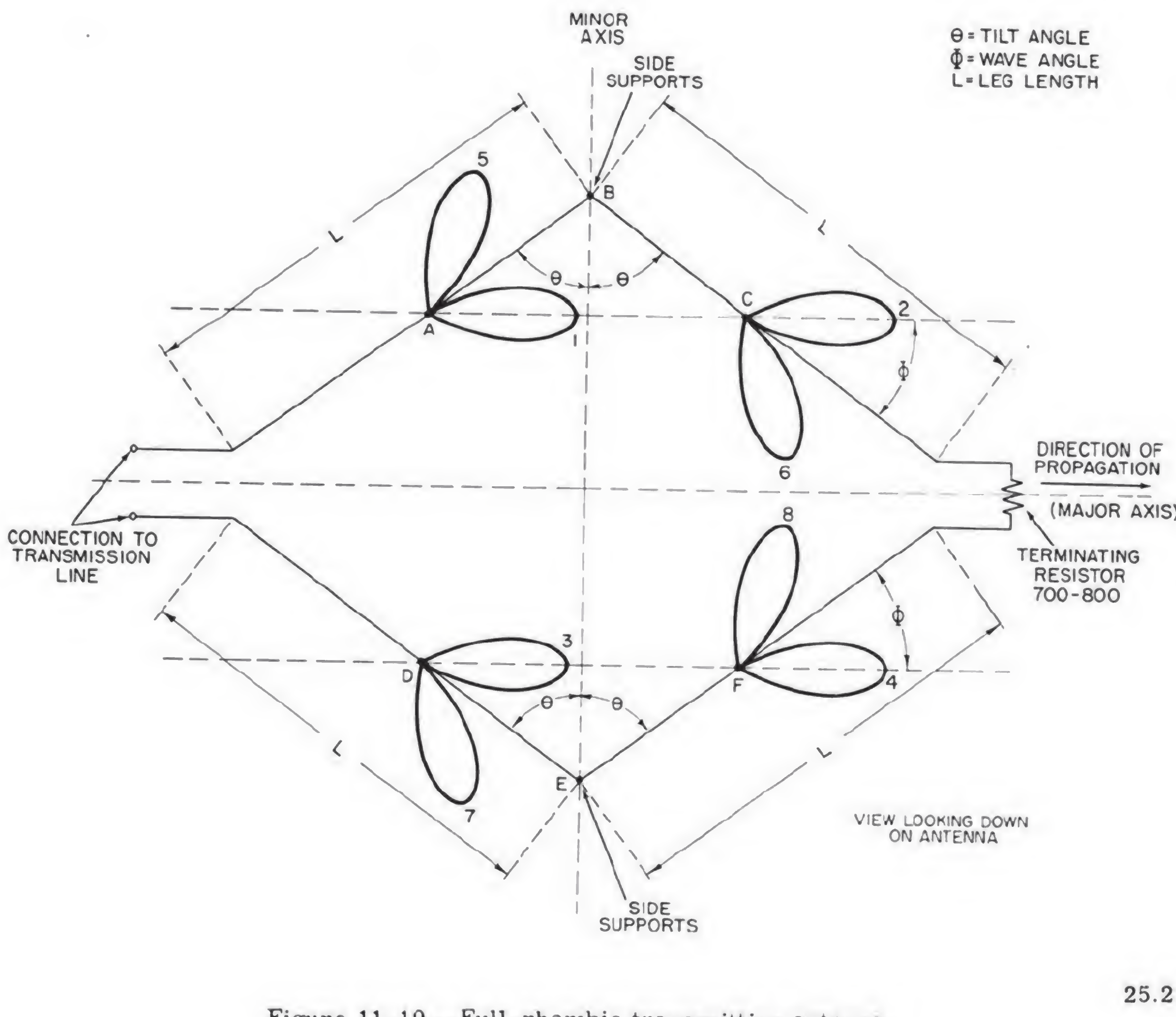

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Figure 11-19.—Full-rhombic transmitting antenna.

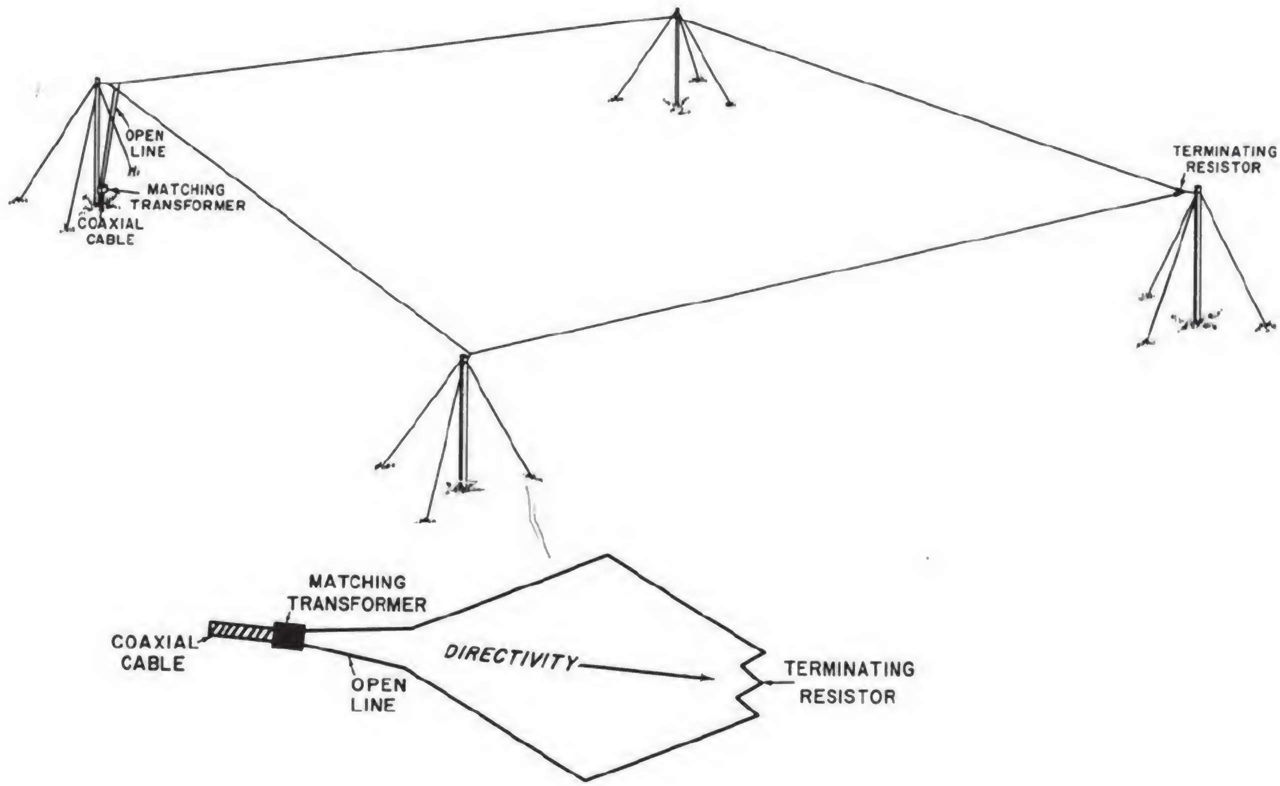

Figure 11-20.—Rhombic antenna.

link can be established with a point 1000 miles away when the wave angle, Φ, is 24°. Determine θ L, and H.

$$\theta = 90° - \Phi = 90° - 24 = 66°$$

$$L = \frac{\lambda}{2 \sin^2 \Phi} = \frac{1}{2 \sin^2 24°} = \frac{1}{2 \times (0.407)^2} =$$

3 wavelengths,

which may be converted to feet by the relation

$$L = \frac{492\ (N-0.05)}{f}$$

where N is the number of half wavelengths, and f is the frequency in megacycles. Therefore

$$L = \frac{492\ (6-0.05)}{10} = 292 \text{ ft}$$

The height is

$$H = \frac{\lambda}{4 \sin \Phi} = \frac{1}{4 \sin 24°} = \frac{1}{4 \times 0.407} =$$

0.615 wavelength.

Because $\lambda = \frac{300}{f}$, the wavelength in meters corresponding to a 10-mc frequency is $\frac{300}{10}$ or 30 m; in feet it is 30 x 3.28 or 98.4 ft.

The height in feet corresponding to 0.615 wavelengths is 0.615 x 98.4 = 60.5 feet.

A rhombic antenna often has two or three conductors in each leg. The conductors are separated by a distance of several feet at the side poles and are brought together at the terminating and transmission end supports. A more nearly constant input impedance is thereby maintained over a relatively wide frequency range.

To obtain a unidirectional pattern the correct terminating impedance must be used.

For receiving low-power transmitting (below 1 kw), noninductive carbon resistors may be used. For high-power work (above 1 kw), carbon resistors are not very satisfactory; ttherefore a stainless-steel dissipation line is used. The stainless-steel conductors are so spaced that the dissipation line will have an impedance equal to the desired terminating impedance of the antenna.

In order to make full use of the broad-band characteristics of the rhombic antenna, the transmission line must likewise have a broad-band characteristic. A transmission line of 700 to 800 ohms would be desired, but such a line would require a spacing of the order of 3 ft, and even though it is nonresonant it would radiate a large amount of energy.

A line of lower impedance could be used along with suitable matching stubs, but the frequency range would be limited. One solution to the problem is to couple a 600-ohm line directly to the antenna input and to ignore the slight mismatch that results.

Double-ended Rhombic

In order to make full use of the bidirectional potential of a full-rhombic receiving antenna it is a common practice to double-end the rhombic. When double-ending the rhombic, each end is terminated in its characteristic impedance (700 to 800 ohms) and transmission lines are connected to each end of the antenna through matching devices. By this manner of double-ending, the antenna may be used to receive two transmissions from opposite directions. Each unidirectional pattern can be used independently by use of the two separate transmission lines.

END-FIRE ANTENNA ARRAY

The end-fire antenna array is so named because the principal radiation is off the ends of the array; that is, the radiation is maximum in the plane of the elements. This array may be contrasted with the broadside array in which maximum radiation is perpendicular to the plane of the elements.

A simple end-fire array employing two vertical half-wave antennas spaced $\frac{\lambda}{2}$ wavelength apart and fed 180° out of phase is shown in figure 11-22. Because the two antennas are $\frac{\lambda}{2}$ wavelengths apart and fed 180° out of phase, radiated energy will reinforce along line 1-2 in the plane of the antennas. Likewise, radiated energy is canceled along line 3-4, broadside to the antennas.

If the spacing of the antennas is reduced to $\frac{\lambda}{4}$ wavelength, and the excitation of A lags that of B by 90°, a cardioid (heart-shaped) pattern is produced, as illustrated in figure 11-23.

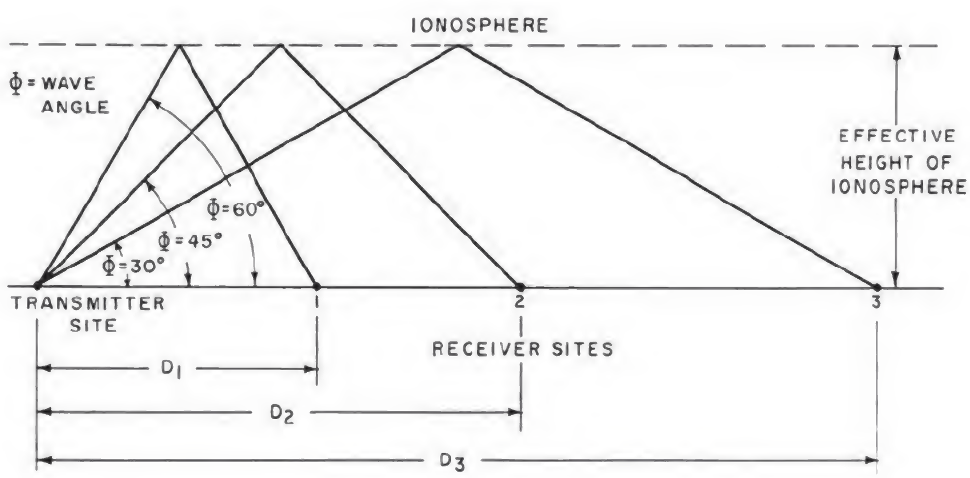

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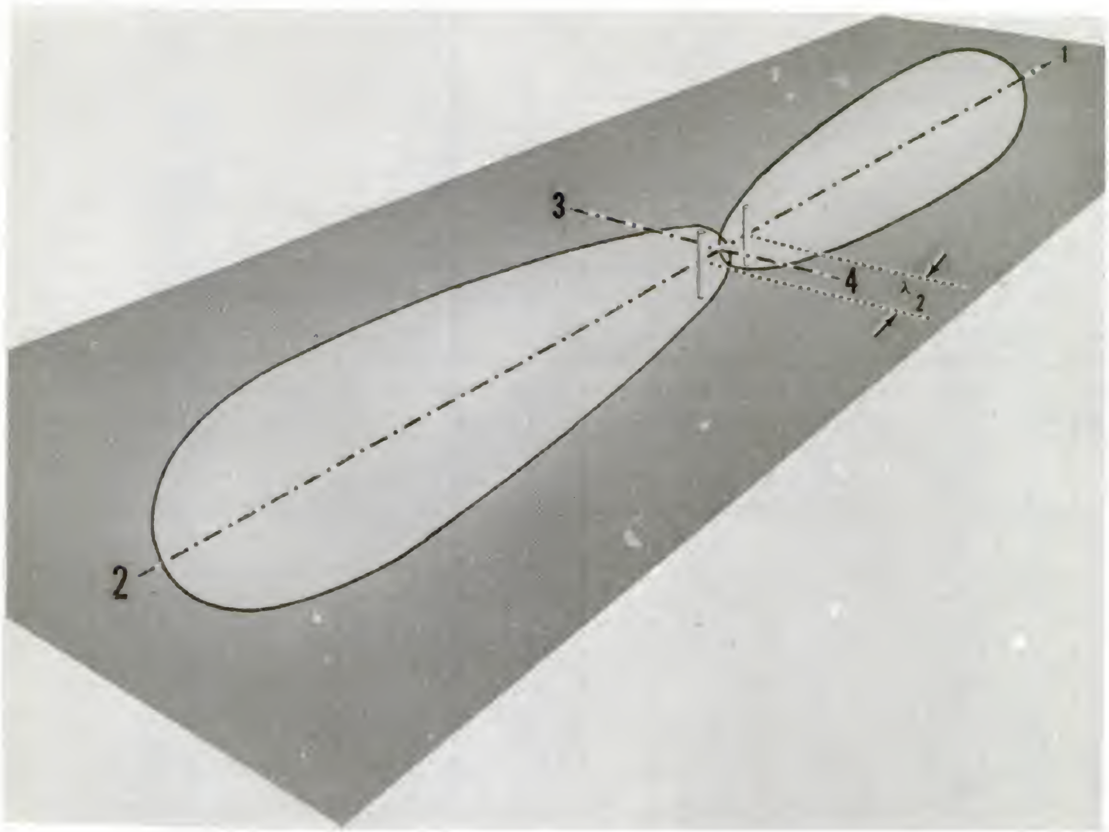
Figure 11-21.—Distance to points of maximum reception as a function to wave angel.



93.28

Figure 11-22.—End-fire array with half-wave spacing.

The cancellation of the radiated energy in the direction of B and the reinforcement in the direction of A may be explained as follows: By the time the radio wave leaving antenna B reaches antenna A, the wave leaving antenna A will have the same phase. Therefore, the two waves will add to produce maximum radiation in the direction shown (in the direction of A). However, by the time the radio wave leaving antenna A reaches antenna B, the wave leaving antenna B will be 180° out of phase, causing cancellation in the direction of B. Maximum radiation occurs in the direction of the antenna that lags.

R-F TRANSMISSION LINES

Basically, an antenna serves to match the impedance of space to the output impedance of a transmitter or to couple the impedance of space to the input impedance of a receiver. Because the antenna is normally some distance from the equipment, a means of transferring (or coupling) maximum power between the antenna and the equipment must be provided. The coupling means is called a transmission line. If at all possible, the impedance of the transmission line and the input impedance of the load are made equal. However, this is not practical in most cases.

Impedance matching devices are used to obtain the proper conditions for transferring maximum power even with wide variations in the original impedances.

The input impedance of a receiver is usually about the same as the transmitter output impedance when conventional coaxial connectors are used. It is often possible to match the transmission line impedance to the input of a receiver or the output of a transmitter by

means of a simple inductive coupling system. In other cases, a more complex system is required.

R-f transmission lines are either flexible or rigid. Both types are used in naval installations, and the type in use is generally determined by the antenna and the individual application.

FLEXIBLE TRANSMISSION LINES

The most common type of flexible transmission line, the coaxial line, has an inner conductor centered in, and insulated from, an outer conductor of larger diameter. The dielectric (insulation) in flexible lines is usually a solid material. It may be in the form of beads or a continuous polyethylene sheath. In addition to providing insulation between the two conductors, the solid material maintains a constant spacing between the inner and outer conductors and thus preserves the characteristic impedance of the line. When a solid dielectric such as polyethylene sheath is used, the dielectric introduces losses in the line. In most flexible transmission lines these losses become progressively greater as the length of the line and frequency increase. At the higher frequencies, steps must be taken to offset the line losses.

Characteristic Impedance

The characteristic impedance of a coaxial air-spaced line (assuming a perfect dielectric) can be found by using the formula shown in figure 11-24. In using this formula, you must know the inside diameter of the outer

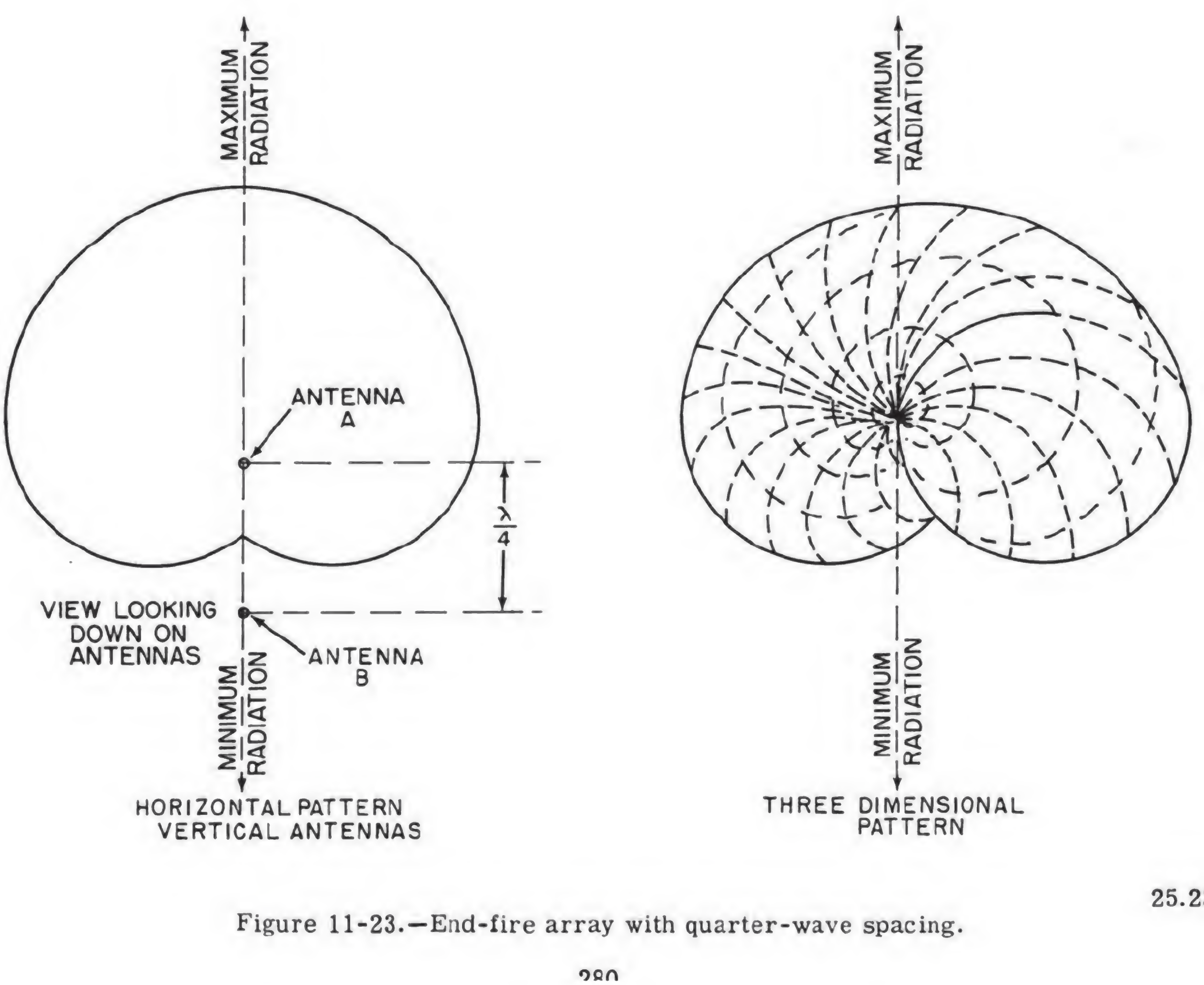


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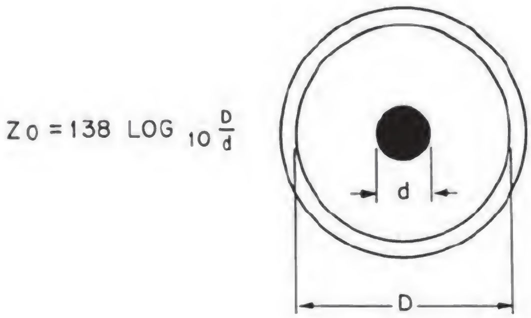
Figure 11-23.—End-fire array with quarter-wave spacing.



1.263
Figure 11-24.—Characteristics of coaxial air-spaced lines.

conductor, D, and the outside diameter of the inner conductor, d. You then find the ratio of the outer conductor size to the inner conductor size by dividing D by d. Next, find the logarithm of this ratio to the base 10 by using a log table or a slide rule. The logarithm of the ratio is multiplied by 138 to find the characteristic impedance of the line. Thus, a line made up of a 1.5-inch outer conductor and a 0.5-inch inner conductor would have a characteristic impedance of 66 ohms. If the inner conductor were 0.25 inch and the outer conductor diameter 1 inch, the characteristic impedance of the line would be 83 ohms.

Physical Versus Electrical Length

As previously mentioned, these impedances are for air-spaced lines and they assume a perfect dielectric. However, there is no perfect dielectric and, because the inner line must be supported, there are losses in all lines. Electromagnetic fields travel more slowly because of the losses, and a correction (velocity factor) must be applied in determining an electrical wavelength. When a reference is made to a half-wave line, the electrical length of the line corresponds to one-half wavelength of the applied signal. The physical length of the line measured with a ruler will always be somewhat less (about 5 percent) than the electrical length in free space. To obtain the physical length, use the formula:

Length in feet (full wave) $\frac{984}{f}$ V where f equals frequency in megacycles, and V equals the ratio of the velocity of the wave in the line to that in free space.

RIGID TRANSMISSION LINES

The characteristic impedance of a rigid line is determined in the same manner as for a flexible line. The electrical differences between the two kinds of transmission lines are decreased capacitance and reduced losses in the rigid line. Because there are open spaces inside the rigid line, condensation becomes a problem. The accumulation of moisture lowers the breakdown voltage of the line and, if enough water accumulates, the line may become short-circuited.

Usually, special fittings are provided so that warm, dry air can be pumped through the line to absorb moisture. In certain installations, the line is filled with an inert gas (such as nitrogen) under pressure to keep condensation to a minimum. When gas-filled lines are used, a pressure gauge is usually installed at a convenient spot so that the line pressure can be watched. A drop in pressure means a leak has developed, and the line should be checked with a soap solution brushed over fittings or suspected spots. If a leak is present and there is some pressure in the line, soap bubbles will appear at the leak.

Special fittings are used for rigid lines so that the line can be brought around corners without disturbing the spacing between conductors. One type of rigid r-f transmission line (waveguide) does not contain a center conductor.

Waveguide Transmission

Waveguides may be rectangular, round, or oval in shape. At the present time, rectangular waveguides are the most common. Although the material in this chapter refers to rectangular waveguides, it can be applied to guides of other shapes. Regardless of the guide shape, a waveguide is a tube through which energy is transmitted in the form of electromagnetic waves. The waveguide need not be metallic; it can be made of dielectric material. However, dielectric waveguides are not often used because the losses of dielectric materials are greater than the losses in metallic guides.

The transmission of an electromagnetic wave along a waveguide is closely related to its transmission through space. At powerline

frequencies, the current flow through the conductors is considered to be the means of transmission of energy, and the external fields are coincidental to that transmission. However, this is not necessarily true at higher frequencies.

Energy can be transmitted along a waveguide with no longitudinal current flow along the guide. The energy is transmitted in the electromagnetic fields, and any current flow in the guide walls is necessary only to provide a boundary for the electric and magnetic fields. It is beyond the scope of this text to prove the foregoing statements; therefore, it is sufficient for you to know that electromagnetic energy is transmitted in the associated fields rather than in the conductor.

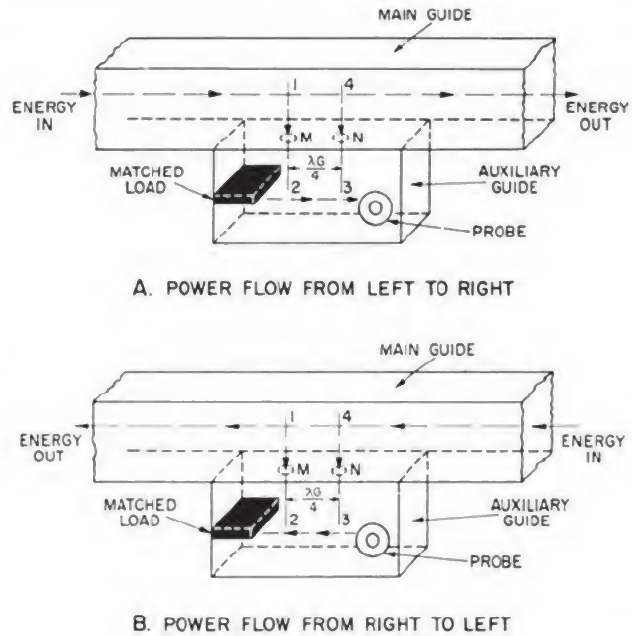
Comparison With Coaxial Transmission

A hollow waveguide has lower losses than either open-wire line or coaxial line in the frequency ranges for which a waveguide is practical. An open-wire line has three kinds of losses: radiation, dielectric, and copper. Coaxial lines do not have radiation loss because the outer conductor acts as a shield, which keeps the magnetic and electric fields between the inner and outer conductors. These lines do have dielectric and copper losses. The waveguide, in comparison, has negligible dielectric loss because it is filled with air. Because of the greater surface area, the copper losses in a waveguide are very small. These losses become greater as the operating frequency is increased because of the skin effect that forces the current to flow in a progressively thinner layer. Even so, this loss is much less than the losses in a coaxial line.

Waveguide Test Measurements

THE DIRECTIONAL COUPLER. – Directional couplers (figure 11-25) are used in radar or microwave systems to extract a small amount of power for test purposes. The amount of power taken from the line is only a small part of the power in the line, but its magnitude must remain proportional to the power in the line. By properly arranging the coupling units, reflected signal power will not affect the accuracy of the tests.

Figure 11-25A is a simplified drawing of a directional coupler. Power from the main



1.264

Figure 11-25.—Directional coupler.

waveguide is taken through two small holes (M and N on drawing) located so as to be one-quarter wavelength apart at the operating frequency. The directional coupler is terminated by a matched load that absorbs any energy reflected to that end of the coupler. The output of the coupler is taken from a probe at the opposite end of the coupler section and is fed through a coaxial cable to the probe in the echo box. Because all of the energy flowing to the terminal end of the coupler section is absorbed by the termination, only the energy in the probe end of the coupler affects the measurements being made.

In operation, energy enters the main guide at the left and travels to point 1. A small part of the energy then goes through hole M and travels to point 2 and then to point 3 and the probe. Another small part of the energy in the main guide travels to point 4 (a quarterwave from hole M) and then to point 3 and the probe. Both of these small portions of the main signal travel the same distance (slightly over one-half wave). Therefore, they are in phase at the probe and may be fed to the measuring device.

Energy that arrives at the matched load from the input by way of hole N, point 3, and

and point 2, travels slightly more than one-half wave farther than energy from the input that arrives over a path through hole M and point 2. Therefore, these two energy components arrive at the load out of phase and cancel.

In figure 11-25B the energy is shown moving from right to left. Energy that moves through hole N, point 3, and point 2 to the load, travels the same distance as energy reaching the load through hole M and point 2. The components reach the load in phase and are absorbed by the load.

Energy that reaches the probe through hole M, point 2, and point 3, travels slightly more than one-half wave farther than energy that reaches the load through hole N and point 3. Therefore, the two components are out of phase and cancel.

THE SLOTTED LINE.—The slotted line, a section of the same kind of material used for the waveguide in the waveguide system (figure 11-26), is used to determine the standing wave (voltage) ratio. The section derives its name from the fact that a slot of uniform narrow width and slightly longer than one wavelength at the operating frequency is milled in one side of the waveguide section. The length of the slot makes it possible to measure two voltage minimums and one voltage maximum, or one voltage minimum and two voltage maximums without the possibility of end effects causing unreliable indications near the ends of the slot.

A carefully machined track is mounted on the slotted section so that a probe mounting can be moved along the track. The track provides a means of maintaining a constant spacing between the probe and the sides of the slot. The distance that the probe is inserted in the line is carefully controlled by a micrometer-type adjustment. This adjustment provides a means of carefully controlling the depth to which the probe is inserted in the line, and the track holds the probe at a constant spacing from the sides of the slot. The depth of probe insertion is held as small as possible in order to keep the probe from causing reflections or arcing. The r-f voltage picked up by the probe is detected by an r-f sensing device (bolometer) and then fed to the VSWR (voltage standing wave ratio) measuring equipment. The standing-wave ratio should not be greater than 1.5 if excessive losses are to be avoided.

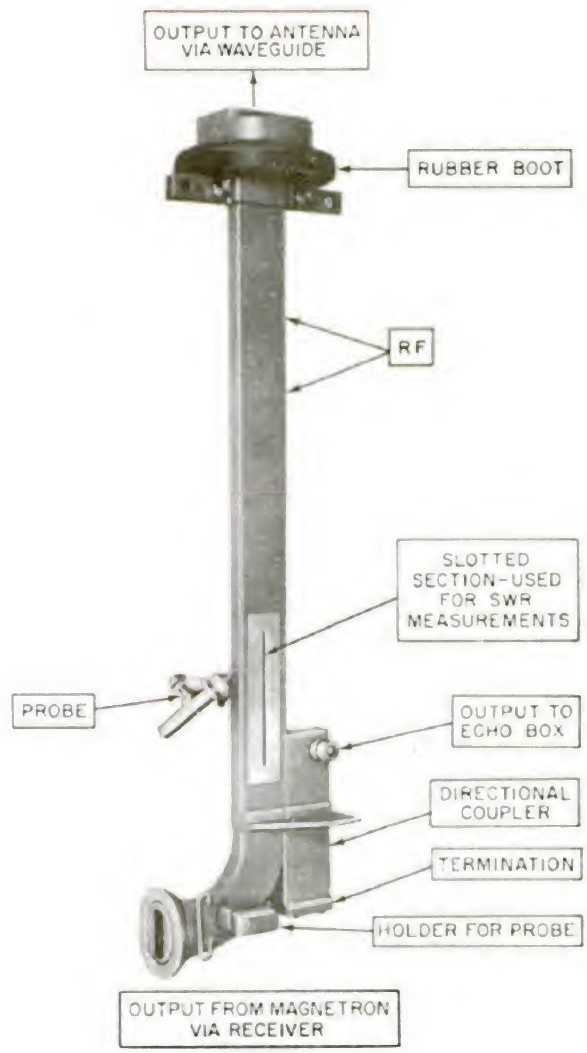


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Figure 11-26.—Slotted line.

MULTICOUPLERS

Because of the large number of receivers included in each individual installation, it is impractical, if not impossible, to use separate antennas for the various equipments because of space limitations. It is possible to use one antenna over a wide range of frequencies provided the antenna system is properly tuned and coupled to the equipment so that the antenna appears as a nonreactive (pure resistance) load. It is also possible to use a coupling system

that allows operation of several transmitters and/or receivers at the same time. It is not, however, normally possible to use an antenna for both transmitting and receiving simultaneously.

One satisfactory approach to the problem of antennas is provided by multicouplers. The multicouplers that are discussed in this chapter are representative of those in current use at naval installations.

HF MULTICOUPLER

Antenna Coupler CU-872/U (figure 11-27) is designed to provide optimum coupling between a single antenna and as many as eight receivers in communication systems. Additional outputs are possible by connecting antenna couplers in cascade. A functional block diagram of the antenna coupler CU-872/U is shown in figure 11-28. A 70-ohm input impedance is provided to match the impedance from the antenna. From the input connector the signal is fed to low-pass/high-pass filters. These filters pass only the frequencies in the spectrum between 2.0 mc and 32 mc. Transformer T1 in the output circuit of the low-pass/high-pass filters provides a transition between the low impedance unbalanced input circuits and a relatively high impedance balanced line. Each side of the balanced line drives one section of the push-pull distributed amplifier.

Tubes V1 through V5, tubes V11 through V15, and their associated circuitry comprise one-half of the push-pull distributed amplifier. Tubes V6 through V10, tubes V16 through V20, and their associated circuitry comprise the other half of the push-pull distributed amplifier. The distributed amplifier sections employ cascade stages along artificial transmission lines to obtain amplification over a wide bandwidth. The cascade amplifiers aid in reducing intermodulation by minimizing odd harmonic distortion. Additionally, employment of the distributed amplifier results in an improved signal-to-noise ratio. The distributed amplifier sections drive transformer T2 in a push-pull manner, thereby reducing intermodulation by minimizing even harmonic distortion. The resulting signal developed across the secondary winding of transformer T2 is applied to a cascaded hybrid network which distributes the amplified signal to eight isolated outputs.

VHF AND UHF MULTICOUPLERS

The CU-255/UR Multicoupler

One antenna coupler widely used is the CU-255/UR. When assembled into a group of two to six units, they provide a system for operating two to six UHF transmitters and/or receivers into or from a single antenna. One coupler is required for each transmitter or receiver. Figure 11-29 shows a group of six multicouplers installed in a rack.

The equipment was designed to operate in the frequency range between 230 and 390 mc. Although it can be used with any transmitter or receiver that covers the frequency range, the AN/GRC-27 and AN/GRC-27-A transceivers are normally used with the coupler group in figure 11-29.

All of the couplers in the group can be tuned manually to any frequency within the limits given above. When they are used with the equipment listed, each tuner may be manually preset to a channel within the band frequencies. It then becomes possible for the operator to dial any preset channel automatically either from the transceiver or on a remote channel selector.

Each CU-255/UR antenna coupler consists of two major components: a coupling cavity or r-f section and an automatic drive mechanism.

The importance of matching impedances has been mentioned previously in this chapter, and the r-f section of the multicoupler is essentially an impedance matching device. It is capable of matching an antenna feedline impedance of 50 ohms to antenna input impedances that mismatch the feedline impedance as much as 2.5 to 1. Thus, the multicoupler provides a means of maximum power transfer between the transmitter and the antenna. The same matching action takes place when the system is used for receiving.

A meter on the front panel of each multicoupler indicates when the unit is correctly tuned. The meter is a part of a reflectometer and indicates the magnitude of the power reflected back from the coupler. When the tuning meter shows zero, there are no standing waves on the transmission line, and the impedances are matched. A standing wave indicator is discussed in a later chapter; a reflectometer will be discussed later in this chapter.

The internal arrangement of a multicoupler is shown in the perspective view of figure 11-30.

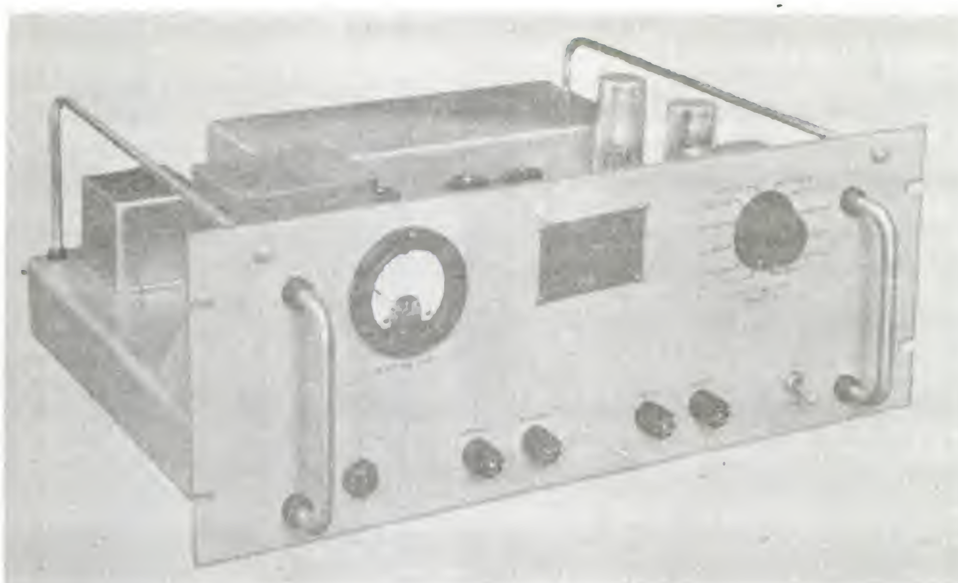

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Figure 11-27.—Antenna Coupler CU-872/U.

The drive mechanism that permits manual and automatic tuning of the coupler fits into the top of the r-f section to form a long thin unit. It can be removed for servicing, when necessary. The normal frequency coverage is from 230 to 390 mc.

Any device inserted into a transmission line will cause some loss, called the insertion loss. The multicoupler introduces an insertion loss of about 1 db over its tuning range. However, the power gained by matching impedances more than compensates for the small insertion loss.

The CU-332/UR

The type CU-332/UR multicoupler covers the same frequency range as the CR-255/UR multicoupler, and both types may be used for either transmitting or receiving. The only difference in the two units is that the CU-332/UR has provision for manual tuning only.

Other Representative Multicouplers

Frequencies between 255 and 400 mc may also be covered with one of the following multicouplers: the CU-284/UR, CU-355/UR, CU-691/UR, and the CU-692/UR.

THE CU-691/UR.—The type CU-691/UR provides for the simultaneous operation of four transmitters or four receivers into, or from, a single antenna. This coupler has four tunable cavities that may be tuned automatically or manually. After the initial setting, the coupler can be retuned by the automatic tuning mechanism. Before the cavity can be manually tuned, it is necessary to loosen the clutch release.

The CU-691/UR multicoupler is completely shielded and does not produce r-f interference. A meter on the coupler indicates when maximum energy is being transferred while transmitting. There is no meter indication when receiving.

THE CU-284/UR.—The type CU-284/UR multicoupler permits simultaneous operation of two UHF transmitters or receivers into a single antenna. It is primarily designed for installation on submarines and small vessels. The coupler is manually tuned and consists of two capacitively tuned resonant cavities, each of which has a 50-ohm terminal impedance.

THE CU-355/UR.—The type CU-355/UR multicoupler has provisions for the simultaneous operation of four u-h-f transmitters and/or receivers into a single antenna on the frequencies between 225 to 400 mc. Either manual or

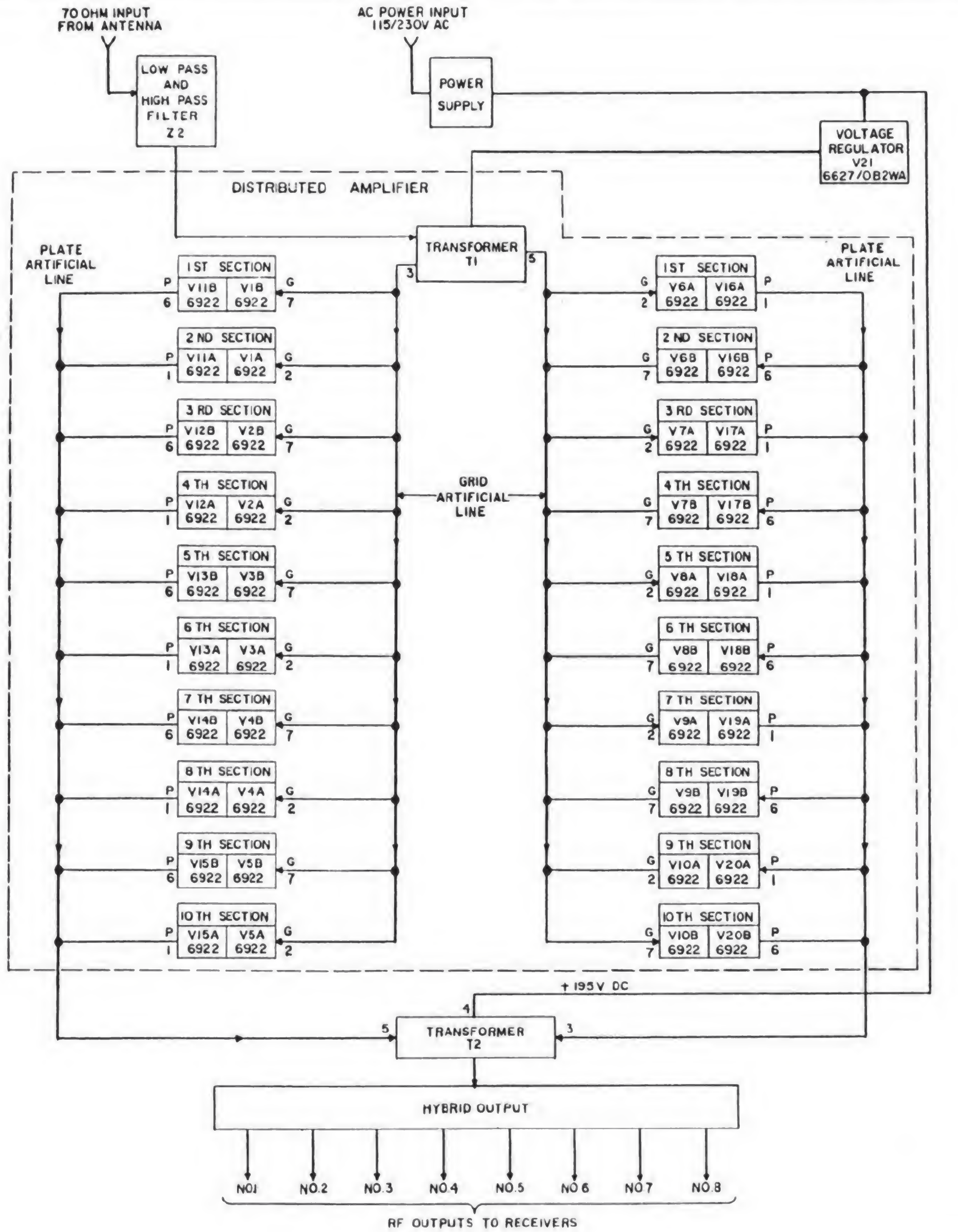

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Figure 11-28.—Antenna Coupl-- CU 8'

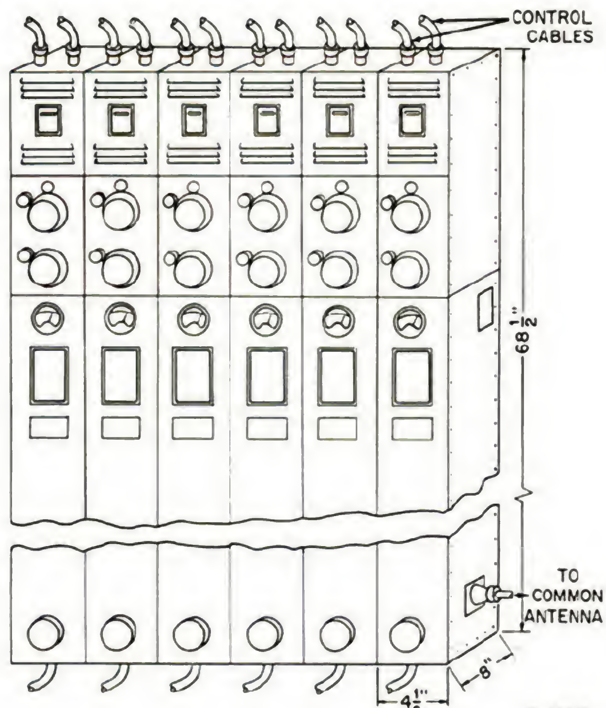

Figure 11-29.—Group of Six Type CU-255/UR Antenna Couplers.

automatic tuning may be used with each of the four cavities. Each cavity has its own power monitor and standing-wave indicator. A 12-position switch on the front panel provides the necessary switching to read the power or standing-wave ratio at any one of the four input connections. The operating frequencies of the units connected to the multicoupler must be separated by one megacycle or more, depending on the characteristics of the auxiliary equipment.

THE CU692/UR.—The fourth multicoupler in the 255-400 mc group is the CU-692/UR, which permits the simultaneous operation of two UHF transmitters or receivers from one antenna. This coupler is similar to the CU-284/UR, except that the CU-692/UR has improved resetability, lower insertion loss, and greater adjacent channel separation. The output impedance of the coupler is 50 ohms.

THE REFLECTOMETER

Most coupler units have a reflectometer, located in the transmission line from the transmitter, to indicate when the tuner is correctly adjusted by indicating the amount of reflected energy on the line. Thus, any mismatch between the coupler and the 50-ohm transmission line is readily apparent, and it can be corrected by retuning the coupler.

Figure 11-31A shows the movable section of the reflectometer separated from the fixed section. The schematic diagram (figure 11-31B) shows how the parts are connected in the moving section. A cable connects the meter to the circuitry of the moving section.

The reflectometer housing is made in the form of a T, and the center conductor of the line passes through the top of the T. The moving part of the bridge slides into the short arm of the T so that the disc is close to the

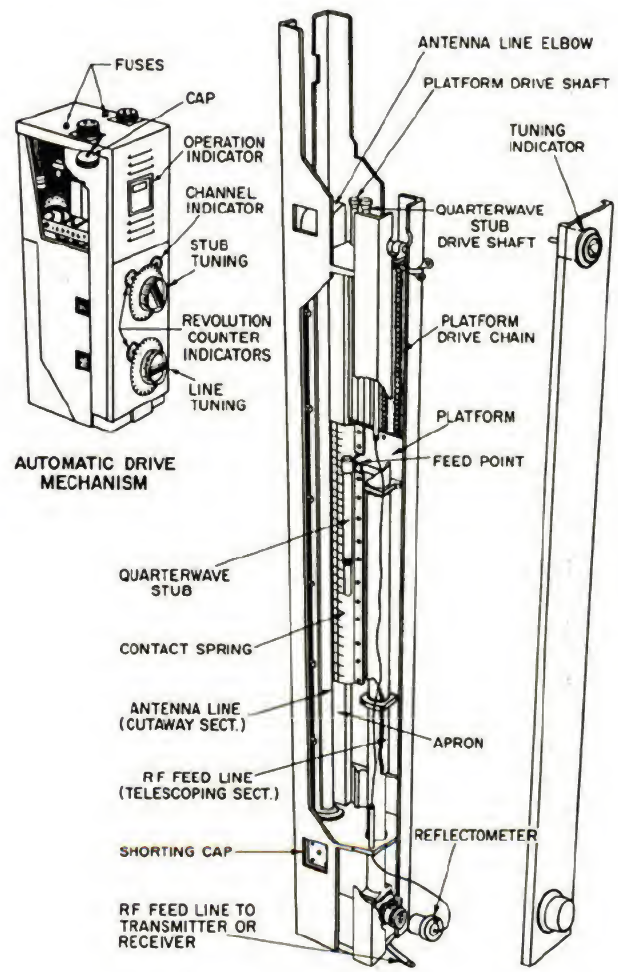

Figure 11-30.—Perspective view of CU-255/UR Multicoupler.

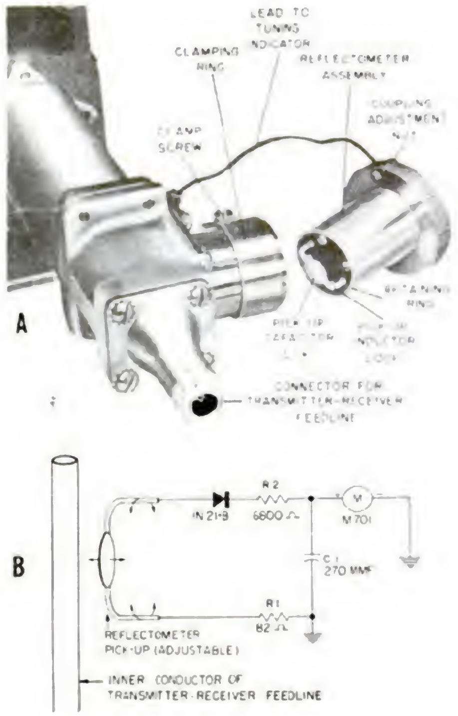

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Figure 11-31.—Reflectometer.

center conductor and capacitively coupled to it. There is also inductive coupling between the loop to which the disc is connected and the center conductor. Because it is necessary to maintain the capacity at the same value when a test is in progress, an adjustable coupling screw passes through the cover of the moving section. The end of this screw rests on a shoulder that is a part of the fixed section and maintains constant spacing regardless of how the movable section is turned. Thus, the movable section can be oriented to adjust the pickup loop in relation to the center conductor of the coaxial line.

Normally, the plane of the U-shaped loop (figure 11-31B) is parallel to the axis of the feedline. One end of the loop is connected to ground through R1, and the other end is connected to a diode crystal detector. R2 is a current limiting resistor and C1 is a r-f bypass for the meter. The meter has a 200-microampere movement and is located on the panel of the coupler. When the reflectometer is in use, the voltage applied to the detector is the vector sum of the components because of inductive and capacitive coupling. As the angle formed by the loop and axis of the feedline changes, the amplitude of the inductive component varies from zero to maximum as the capacitive component remains unchanged. The phase of the inductive component is reversed by turning the loop through 180 degrees. Therefore, at some orientation of the loop, the currents (because of the two components) will cancel.

The same cancellation can be obtained by leaving the loop parallel to the feedline axis and adjusting the position of the capacitive plate by turning the adjustment screw in or out until cancellation occurs. This will happen when there is no reflected wave on the feedline because (1) the capacitive coupling is very small, (2) the loop inductance is negligible compared to the resistance of R1 (82 ohms), and (3) R1 is noninductive.

After cancellation has been obtained, as indicated by a zero meter reading, the movable section is clamped in position. Therefore, zero meter reading indicates the impedances are matched and maximum power is being transferred.

There is some hazard in using this method however, because a mistuned coupler can cause a high standing-wave ratio, which would produce enough reflectometer current to burn out the microammeter and crystal diode.

A more practical method of using the reflectometer is to tune the transmitter and coupler for minimum standing-wave reflection and then use the reflectometer for final fine tuning. Usually zero readings will not be obtained, but a minimum of two to six microamperes can be accepted as an indication of correct tuning.

CHAPTER 12

COMMON OPERATING ADJUSTMENTS OF RADIO TRANSMITTERS

The CT M must know how to make operating adjustments on many types of electronic equipment. This equipment includes communication transmitters, receivers, and associated TTY and FAX equipment. Common operating adjustments include starting and stopping the equipment, tuning it, and selecting the operating frequency. Meter readings of current, voltage, and power must be taken; gain-control or intensity-control adjustments must also be made. The knowledge of how to perform these functions is basic to the CT M's knowledge of maintenance and repair, because without it he can do little to maintain or repair equipment.

The common operating adjustments are made by means of external controls. Other chapters in this training course describe various electronic circuits associated with external controls and analyze their functions. The purpose of this chapter is to describe the common operating adjustments for radio communications equipment.

The method of approach in treating each class of electronic equipment is to give, first of all, a picture of a typical equipment and a general description of its functions. Next, a block diagram of the equipment showing the major components and their interconnections, together with a description of their functions, is given. Finally, the common operating adjustments are described in detail.

This method of approach has the advantage of showing the CT M why certain adjustments are made rather than merely telling him how they are made. How to make adjustments on electronic equipment is spelled out in detail in the equipment instruction book.

In addition to making common operating adjustments on a variety of electronic equipments, the CT M must be able to perform the necessary switching operations at a switchboard to connect an equipment to a remote control point or to another equipment. The circuits for a variety of switching operations are analyzed in another chapter of this training course.

NECESSITY FOR FAMILIARITY WITH EXTERNAL CONTROLS

In modern warfare no commander can exercise control of more than a handful of men by his physical presence. To receive information upon which to base decisions, to transmit commands, and to keep his command in all respects ready to perform assigned NAVSECGRU functions, the commanding officer must rely on communications. In this day of huge task forces and armadas of supporting aircraft, effective communications mean radio communications.

Communications equipments include low, high, and very high-frequency, and ultra-high frequency transmitters and receivers. The low- and high-frequency high-power transmitters are used for long-range communications. The very high-frequency, low-power transmitters are used for short-range communications. Communications receivers are usually of the superheterodyne type and are somewhat similar to broadcast radio receivers, except that the communications receivers have much greater selectivity and sensitivity and cover a greater band of frequencies. The receiver must be properly tuned, the gain control correctly adjusted, the BFO operating correctly, and many other adjustments made by means of the external controls in order to have satisfactory performance.

A transmitter or receiver not properly tuned may mean a break in a communications chain, the loss of a vital message, and the difference between success and failure of a mission. The CT M must back up the operators of electronic equipments and be prepared to lend a hand in making the necessary adjustments for top performance; this requirement is in addition to his

other duties of troubleshooting, maintenance, and repair.

COMMON ADJUSTMENTS AND CONTROLS

Before the CT M can ascertain that an equipment is working properly he must be able to perform the following actions: (1) starting and stopping the equipment, (2) tuning the oscillator by varying the inductance or capacitance in the oscillator tank circuit, (3) tuning the various r-f amplifier stages progressively from the stage next to the oscillator to the final power amplifier by varying the capacitance or inductance in the associated tank circuits, (4) tuning the antenna by varying the inductance or capacitance in the antenna tuning circuit, (5) matching the antenna to the antenna feed line by varying the mutual inductance in an autotransformer coupling circuit, (6) varying the load on the transmitter by adjusting the coupling mutual inductance between the antenna feed line and the transmitter (7) manual or machine keying the transmitter and (8) modulating the r-f carrier with voice or teletype signals.

Actions commonly performed by the CT M relating to communications receivers include (1) tuning the receiver by adjusting the capacitance in the r-f amplifier and local oscillator resonant tank circuits, (2) band switching by changing the inductance in the r-f amplifier and local oscillator resonant tank circuits, (3) adjusting the r-f and a-f signal levels by varying the r-f and a-f gain control potentiometer, (4) switching on or off the beat frequency oscillator (BFO), (5) tuning the BFO by adjusting the capacitance in the associated tank circuit, (6) switching on or off the receiver silencer, and (7) adjusting the tone control circuits in the associated noise suppressors by varying the capacitance shunted across the audio circuits.

NECESSITY FOR CAREFUL STUDY OF TECHNICAL MANUALS

Every piece of electronic equipment has an instruction book (technical manual) that completely describes the equipment. The first step in becoming acquainted with an electronic equipment, whether it be a communications transmitter or receiver, is to break out the technical manual for that particular equipment and study it carefully.

The technical manual contains valuable information, which is not always used to best advantage simply because it is not studied carefully.

Instruction books are usually arranged in sections beginning with a general description (section 1), followed by theory of operation (section 2), installation procedures (section 3), operational procedures (section 4), operator's maintenance (section 5), preventive maintenance (section 6), corrective maintenance (section 7), and a parts list (section 8). Detailed wiring diagrams and schematics are also included in the last part of the instruction book. Frequently, simplified schematics are included with the discussion of theory of operation.

The arrangement and content of the technical manual should be closely observed. It is not necessary to memorize the data. However, make mental notes of the purpose and use of each section.

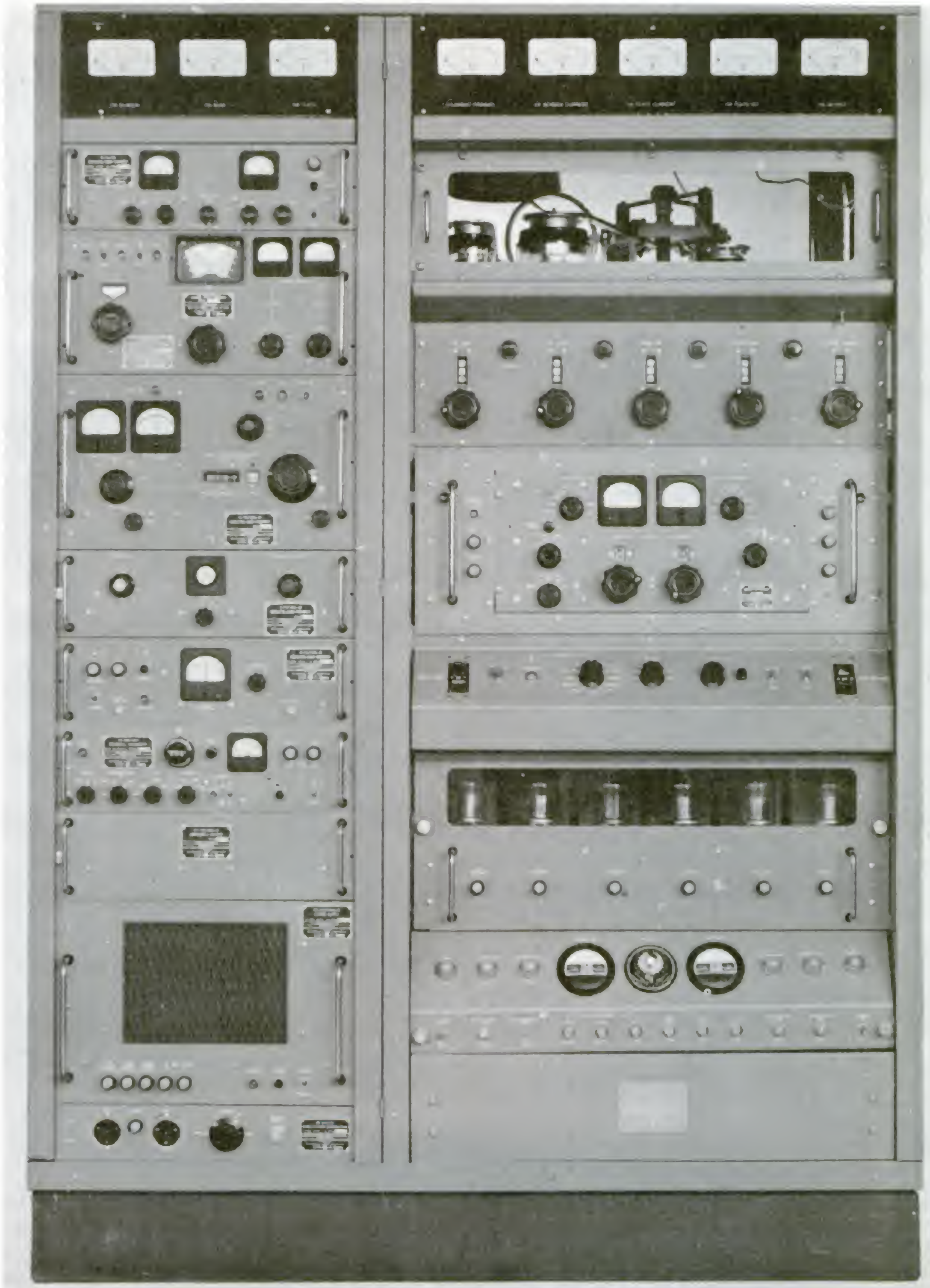
For example, there may be a data sheet containing information about relay coils and contacts. Or, there may be a paragraph detailing the information that should accompany an order for a renewal part. Make a note of this, and the general nature of the data, for possible future use. The more familiar the CT M is with the instruction book, the easier his work will be and the more time he can save in an emergency.

The schematic and interconnection wiring diagrams should be studied carefully. Be able to identify any part that is illustrated. Parts that cannot be readily identified at first can be identified later by studying the parts list. The system of symbols used should be learned. This is particularly important when a symbol has been assigned to each pair of contacts on a relay or switch. Sometimes several devices operate from the same control; the method of showing this on the diagram should be noted. Determine the best use to which the schematic, wiring, and interconnection diagrams can be put.

Where circuit cabling is used, the individual leads are identified as they enter and leave the cable. For example, in one particular equipment the lead from terminal 3 of potentiometer R257B extends to jack J260D via a cable. Where the lead enters the cable it is marked J260D. Where it leaves the cable it is marked R257B.

TYPICAL RADIO TRANSMITTER

The following sections describe the operating adjustments of the radio transmitter, AN/FRT-39 (figure 12-1). Comparable operating



1.330X

Figure 12-1.—Front View, Model GPT-10K (Synthesized), AN/FRT-39.

adjustments of similar types of radio transmitters will be found in the "Operation" section of the technical manual for that particular equipment. In an instruction book, the operation section is usually chapter 4.

RADIO TRANSMITTING SET AN/FRT-39

General Description

The radio transmitter set AN/FRT-39 is a general purpose radio communications transmitter capable of providing 10,000 watts peak envelope power (PEP) output throughout a frequency range of 2 to 28 mc. The principle function of the equipment is to provide long range communications from shore-to-ship or point-to-point by the single-sideband type of operation. The equipment may also be used for the following types of transmission:

(1) CW (keyed carrier)
(2) Frequency-Shift Carrier
(3) Single-Sideband Suppressed Carrier
(4) Double-Sideband Suppressed Carrier
(5) Independent Sideband (separate intelligence)
(6) Single- or Double-Sideband (with carrier)

Protection for operating and maintenance personnel, as well as protection against equipment damage caused by overloads or other equipment faults, is furnished through the use of interlocks and overload relays.

The AN/FRT-39 is constructed in two basic sections, the main frame and the auxiliary frame. The main frame is located to the right of the auxiliary frame and houses the power amplifier (PA), the intermediate power amplifiers (IPA), the main power supply and high voltage section, the PA loading and tuning controls, the relay and indicator control panels, and the meter panel. The auxiliary frame is located to the left of the main frame and houses all of the sideband exciter equipment, exciter power supply equipment, and other control equipment for the various modes of operation.

The Auxiliary Frame Components

The block diagram of the AN/FRT-39 (figure 12-2) illustrates the auxiliary frame (AN/URA-30) components in the dotted area to the left of the figure. The auxiliary frame components consist of the sideband exciter (CBE), power supply (CPP-1), radio frequency amplifier (CHG), controlled master oscillator (CMO), controlled oscillator (CLL), primary standard (CSS), tone intelligence (TIS), divider chain (CHL), and the main power supply (CPP-2). The parenthetical designators are those assigned by the manufacturer and are not standard Navy terminology.

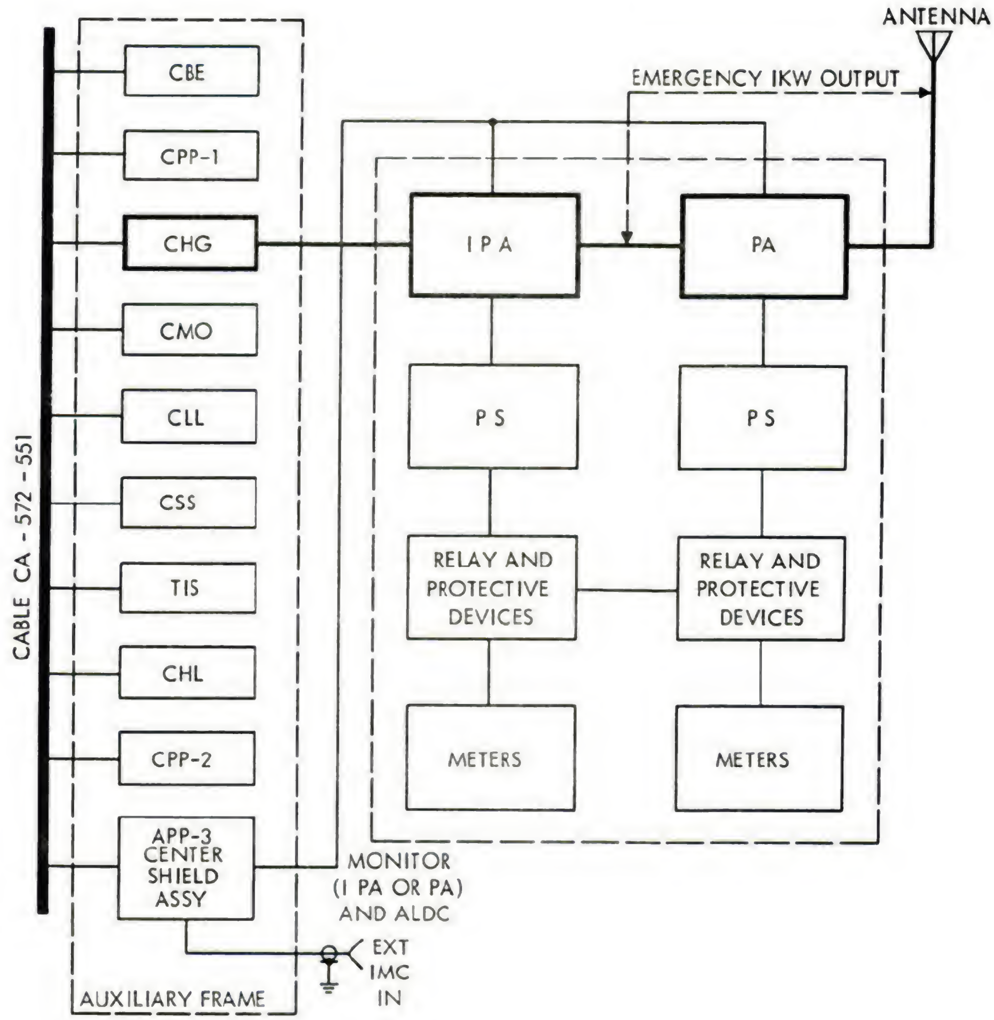
The r-f signal and all of the modulating components of the signal are generated by the above mentioned units and amplified by the r-f amplifier and coupled to the IPA in the main frame.

SIDEBAND EXCITER, CBE.—The sideband exciter (figure 12-3) will accept two channels of intelligence each having a bandwidth of 7.5 kc and processes them for modulation of an intermediate sideband carrier (250 kc). The 250 kc carrier is generated in the regenerative divider network, which is part of the radiofrequency amplifier. The two 7.5 kc intelligence channels are used to modulate the upper sideband (channel 1) and the lower sideband (channel 2).

POWER SUPPLY, CPP-1.—The power supply for the sideband exciter (figure 12-4) is mounted behind the auxiliary frame and supplies 200 volts unregulated and 150 volts regulated d-c outputs.

RADIO FREQUENCY AMPLIFIER, CHG.—The radio frequency amplifier (figure 12-5) is provided with two signal inputs: the sideband exciter, and the controlled master oscillator. The sideband exciter frequency is 250 kc $\pm$ 7.5 kc and the controlled master oscillator frequency is from 2 to 4 mc. The input frequencies are modulated and subsequently heterodyned by additional precise frequencies in order to bring the final r-f output into the 1.75 to 33.75 mc range. The additional precise frequencies are generated within the r-f amplifier unit and are derived from an accurate 1 mc standard. As noted in the beginning of this section the overall frequency range of the transmitter is only 2 to 28 mc due to the frequency limitations of the main frame amplifiers.

CONTROLLED MASTER OSCILLATOR, CMO.—The controlled master oscillator (figure 12-6) supplies precise frequencies to the r-f amplifier in the 2 to 4 mc range. The accuracy of the output frequency is derived from the precise 1 mc standard.



1.331X

Figure 12-2.—Block Diagram, Model GPT-10K (synthesized), AN/FRT-39.

1.332X

Figure 12-3.—Sideband Exciter, CBE.

1.333X

Figure 12-4.—Power Supply, CPP-1.

1.334

Figure 12-5.—Frequency Amplifier, CHG.

1.335X

Figure 12-6.—Controlled Master Oscillator, CMO.

CONTROLLED OSCILLATOR, CLL.–The controlled oscillator (figure 12-7) provides the low frequencies in 100 cps steps for stabilizing the controlled master oscillator. These frequencies are in the range of 510 to 519.9 kc and are fed to the master oscillators phase detector to frequency stabilize the master oscillators 2 to 4 mc output in the 100 cycle and 1,000 cycle steps.

PRIMARY STANDARD, CSS.–The primary standard (figure 12-8) is a precision oscillator within a temperature controlled oven containing transistors, zenner diodes, and other elements. The oscillator has to frequency stabilize the one part in 10^8 per day. The frequency output of the primary standard is 1 mc and is used to regulate the controlled master oscillator and the control oscillator stability.

DIVIDER CHAIN, CHL.–The divider chain (figure 12-9) is used to count down the primary standard 1 mc output by using flip-flop multivibrators. The output frequencies available from the divider chain are: 10 kc, 1 kc, and 100 cps.

POWER SUPPLY, CPP-2.–The CPP-2 power supply (figure 12-10) provides:

a. + 380 volts unregulated
b. - 400 volts unregulated
c. + 160 volts regulated

1.336X

Figure 12-7.—Controlled Oscillator, CLL.

Figure 12-8.—Primary Standard, CSS. 1.337X

Figure 12-9.—Divider Chain, CHL. 1.338X

Figure 12-10.—Power Supply, CPP-2. 1.339X

d. +75 volts regulated
e. - 6 volts regulated
f. 6.3 (AC) volts regulated

TONE INTELLIGENCE UNIT, TIS-3.-The Tone Intelligence Unit (figure 12-11) accepts three types of d-c signals (FSK, CW, FAX) and converts them into audio frequency output signals for sideband transmission via an associated sideband generator unit that provides its RF sideband transmitter with the required RF intelligence.

Main Frame Components

A block diagram of the transmitter is illustrated in figure 12-2. The r-f carrier is originated in the auxiliary frame and is fed to the intermediate power amplifier in the main frame. The 1 kw output of the IPA is then fed to the PA which in turn is coupled to the antenna via the antenna coupling and loading circuits.

RADIO FREQUENCY AMPLIFIER.-The r-f amplifier which consists of a first amplifier stage (class A), a second amplifier stage (class A), and an intermediate power amplifier (class AB1), is commonly called the IPA. The input to the first amplifier stage is supplied by a sideband exciter operating in the frequency range of 2 to 28 mc. As explained earlier, the exciter is located on the auxiliary frame chassis.

The IPA is manually tuned/loaded and includes a multimeter with switching capabilities for direct reading of d-c and r-f voltages or currents. A second meter is mounted on the front panel for the purpose of reading the IPA plate current. The IPA front panel also consists of the following controls:

(1) IPA BAND switch
(2) IPA GRID TUNING capacitor
(3) 1ST AMPLIFIER TUNING capacitor
(4) DRIVER BAND switch
(5) IPA LOADING switch
(6) IPA TUNING capacitor
(7) IPA TUNING indicator
(8) IPA LOADING capactior
(9) IPA LOADING indicator
(10) Screwdriver neutralizing adjustment capacitor

The IPA is rated at 1 kw r-f output and can be fed to the PA or independently to an antenna by bypassing the PA when it is desirable to operate the transmitter at a maximum power output of 1 kw.

POWER AMPLIFIER.-The PA consists of one vacuum tube operating class AB1 and is rated at 10 kw. The PA is a grounded grid amplifier since the IPA input is applied to the PA cathode. Tuning and loading of the PA output network is accomplished with the PA TUNE capacitor, PA LOAD capacitor, tapped inductance coils, OUTPUT balance capacitor, and the output loading inductors which are tuned by ferrite slugs. PA switching is accomplished by a band switch which progressively shorts out sections of the tuning inductance. Either balanced or unbalanced output is available by the use of jumpers on the OUTPUT LOADING inductors.

1.340X

Figure 12-11.—Tone Intelligence Unit, TIS-3.

A number of meters and tuning controls associated with the PA appear as follows:

Meter Panel.–
(1) FILAMENT PRIMARY voltage
(2) PA SCREEN current
(3) PA PLATE current
(4) PA PLATE r-f
(5) PA OUTPUT
(6) PA SCREEN VOLTAGE
(7) PA BIAS VOLTAGE (grid)
(8) PA PLATE VOLTAGE

PA Controls.-
(1) PA TUNE knob
(2) PA LOAD knob
(3) BAND SW knob
(4) OUTPUT BAL knob
(5) OUTPUT LOADING knob
(6) AC POWER indicator
(7) TUNE indicator
(8) OPERATE indicator
(9) PLATE ON indicator

RF AMPLIFIER POWER SUPPLY.–The r-f amplifier power supply consists of a high voltage rectifier and a bias rectifier. The high voltage rectifier is a full-wave rectifier using a 5R4 vacuum tube. The high voltage rectifier supplies unregulated plate voltage to both the first and second r-f amplifiers. It also supplies unregulated screen voltage for the IPA, first, and second r-f amplifiers. The bias rectifier is a half wave rectifier using 6X4 vacuum tube. It supplies -300 volts for the PA grid and PA bias relay. The relay provides protection for the PA in the event of bias failure. The bias rectifier also supplies -150 volts bias for the first, second, and intermediate power amplifiers. The power supply also supplies filament voltage for the IPA's.

PA HIGH VOLTAGE POWER SUPPLY.–The PA high voltage power supply circuits consist of high voltage rectifier tubes, circuit breakers, control equipment, 50 and 60 cycle power transformers, filament transformer, choke coils, high voltage capacitors, blower motors, and other miscellaneous components. The power supply provides 7.5 kv PA plate voltage, 1.2 kv PA screen voltage, PA filament voltage, and 3 kv IPA plate voltage.

RELAY AND INDICATOR CONTROL PANELS.–The relay and indicator control panels are equipped with control circuits for the purpose of disabling the transmitter when serious or abnormal conditions prevail. For example, the transmitter should not be powered if any interlock switch is open, or if any of the transmitter circuits receive overvoltages. The relays are also used to apply voltage to the various circuits in proper sequence. For example, the PA plate voltage should not be applied before the PA filament has had sufficient time to reach the proper operating temperature.

Common External Adjustments

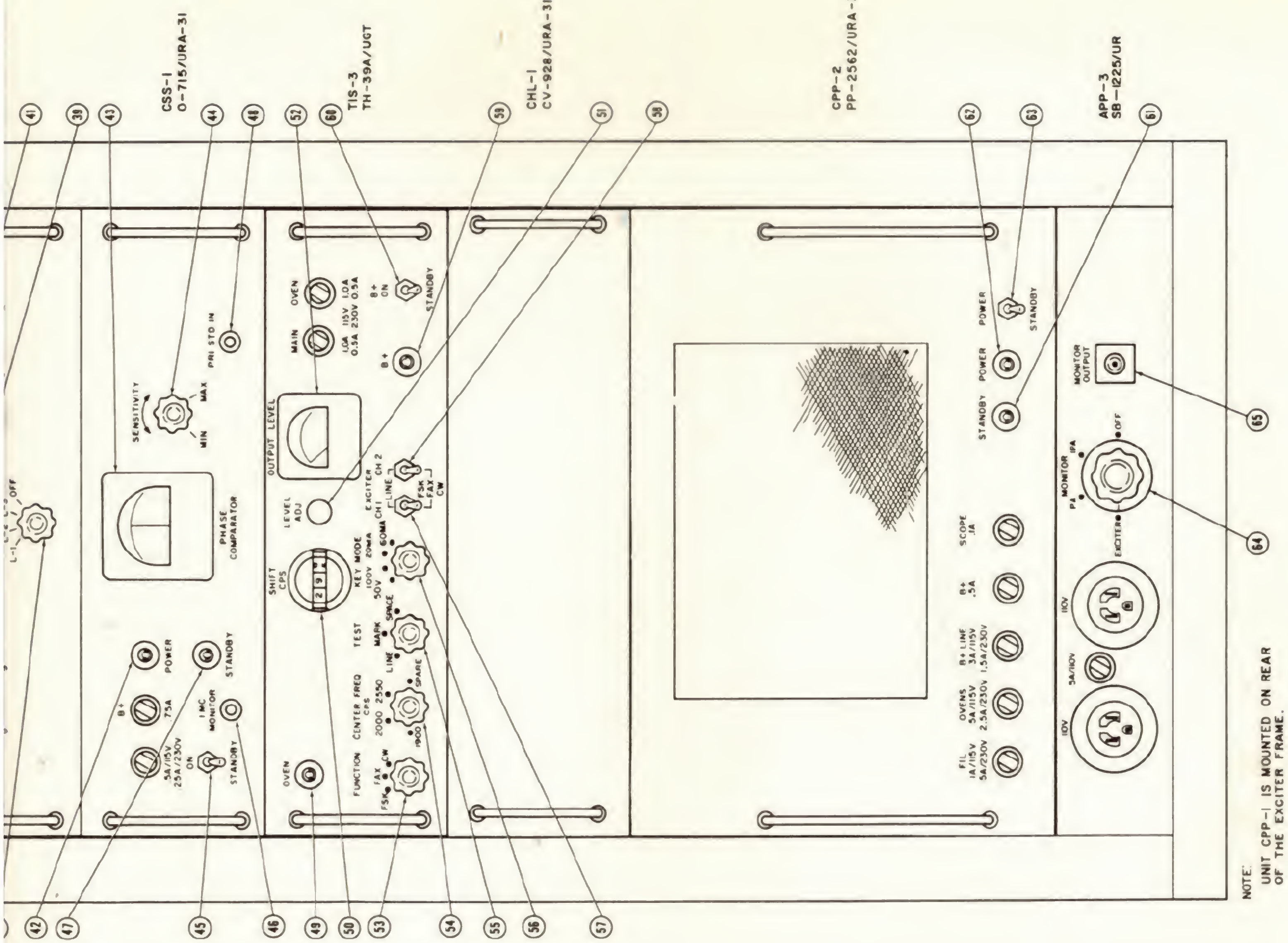
The following section will describe the basic external control adjustments for proper operation of the AN/FRT-39 transmitter. The step by step procedures will be covered in two subsections relating to the auxiliary frame and the equipment main frame.

AUXILIARY FRAME.–The many controls on the synthesized exciter/sideband generator provide flexibility and ease of operation. To properly operate the auxiliary frame a prescribed order of tuning is mandatory. Table 12-1 lists the operating steps and control numbers. For location of the controls concerned see figure 12-12.

Steps 0-10 table 12-1 indicate a recommended turn-on procedure. From a cold start, the rack should have a warm-up time of 48 hours. A shorter warm-up time assumes STANDBY operation in idle periods. To simplify instructions, a tune-up on carrier at 7,001,500 cps is given; tune-up at other carrier frequencies should be readily apparent from the 7,001,500 cycle tune-up procedure.

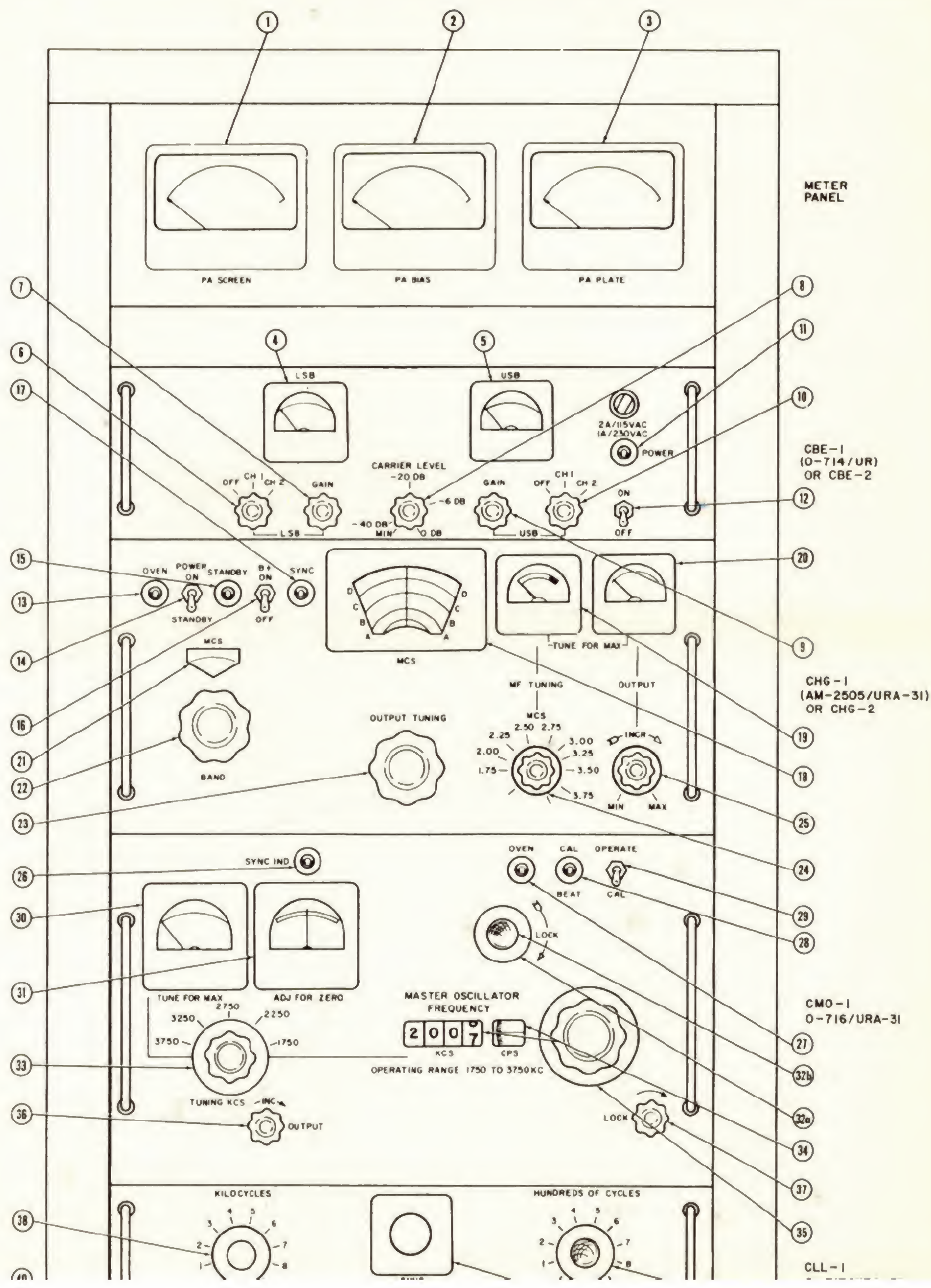
Steps 11 and 16 are settings required for the 7,001,500 cps carrier; control 38 in position 1 agrees with the kilocycle digit in 7,001,500; control 41 in position 5 agrees with the hundreds digit in 7,001,500. Steps 11 through 16 indicate check operation of the low frequency loop (CLL).

Steps 17 through 27 enable the control master oscillator (CMO) to supply the proper output frequency. The CMO contains a calibrated circuit of a 100 kc oscillator equipped with a reactance tube, mixer, beat indicator, and phones. By carrying out step 17, the 5.75-7.75 band on control 21 indicates 4, a 4 mc differential. Consequently, the CMO must provide 7,001,500 cps less 4,000,000 cps



1.341X

Figure 12-12.—Location of Controls on Sideband Generator, Auxiliary Frame, AN/URA-30 of the AN/FRT-39.


METER PANEL
PA SCREEN
PA BIAS
PA PLATE
CBE-1 (O-714/UR) OR CBE-2
LSB
USB
2A/115VAC 1A/230VAC
POWER
CARRIER LEVEL
-20 DB
-6 DB
-40 DB MIN
0 DB
OFF CH 1 CH 2
GAIN
ON OFF
CHG-1 (AM-2505/URA-31) OR CHG-2
OVEN
POWER ON
STANDBY
B+ ON
OFF
SYNC
MCS
BAND
OUTPUT TUNING
TUNE FOR MAX
MF TUNING
OUTPUT
INCR
MIN MAX
1.75 2.00 2.25 2.50 2.75 3.00 3.25 3.50 3.75
CMO-1 O-716/URA-31
SYNC IND
CAL
OPERATE
BEAT
LOCK
ADJ FOR ZERO
MASTER OSCILLATOR FREQUENCY
2007
KCS
CPS
OPERATING RANGE 1750 TO 3750KC
3750 3250 2750 2250 1750
TUNING KCS
INC
CLL-1
KILOCYCLES
HUNDREDS OF CYCLES

or 3,001,500 cps. The nearest checkpoint to 3,001,500 cps is 3,000,000 cps and the CMO should be calibrated at 3 mc as shown by step 19. Steps 20 and 21 merely (a) readjust the CMO for the approximate 3,001,500 cps output and (b) lock the calibrate adjustment. Steps 22 through 27 (a) tune the CMO for the setting in step 20, (b) lock the MASTER OSCILLATOR FREQUENCY dial, and (c) provide a workable synthesized output level from the CMO.

At this point, the master oscillator (CMO) output is 3,001,500 and the primary standard (CSS) is powered and operating since the divider chain (CHL) and controlled oscillator (CLL) in the low frequency loop are properly functioning; therefore, only the high frequency loop (CHG) remains to be tuned. Perform step 29 to provide the CHG with a 250 kc carrier. The high frequency loop circuits heterodyne the synthesized output from the control master oscillator to produce the desired output frequency. However, the CHG balanced modulator needs tuning which is done as shown in step 30. Steps 31 through 34 tune the CHG's output circuit for the desired frequency and provide an output level of one watt.

MAIN FRAME.–The sideband exciter (CBE in the auxiliary frame) is now tuned and ready for additional amplification and final tuning/loading in the main frame. It is recommended that the units located in the main frame chassis be initially tuned and loaded on carrier. Afterwards, the initial adjustments may be refined, according to the mode of operation desired, in order to meet rated power output and distortion requirements.

The step-by-step tuning/loading procedure for the main frame is described in Table 12-2. The control numbers referred to are shown in figures 12-13 through 12-17 for the individual units concerned.

Table 12-1. —Tuning/Loading Procedure for Auxiliary Frame.

Step	Control No.	Control Designation	Operation	Purpose
0	63 60 57, 58 45 40 29 14 16 12	POWER/STANDBY B+ EXCITER ON/STANDBY SYNC OPERATE/CAL POWER B+ ON/OFF	STANDBY STANDBY LINE (CH 1, CH 2) STANDBY OFF CAL STANDBY OFF OFF	In turning power on to the equipment, the filaments of all vacuum tubes should be heated before the plates receive voltage. This step and the following nine insures this condition. Before operating the equipment, allow sufficient time for ovens 13, 27 and 49 to cycle. Step 0 will keep the ovens warm without expenditure of plate power; plate power is expended in steps 1 through 9.
1	63	POWER/STANDBY	ON	Supplies power to rack components.
2	60	B+	ON	Powers TIS-3.
3	57, 58	EXCITER	LINE (CH 1, and CH 2)	Feeds audio on channels directly to CBE.
4	45	ON/STANDBY	ON	Powers CSS-1.
5	40	SYNC	OFF	
6	29	OPERATE/CAP	CAL	In preparation for step 18.
7	14	POWER	ON	Powers part of CHG.
8	16	B+	ON	Powers part of CHG.
9	12	ON/OFF	ON	Powers part of CBE.
10	The following is a tune up of synthesized exciter on carrier at 7,001,500 cps output frequency (F out). The procedure for other carrier frequencies is readily apparent from the example given below. Steps 11 through 16 check that the divider chain CLL is properly operating.			
11	38	KILOCYCLES	POSITION 1	Corresponds to the 1-kc increment in the 7,001,500 F out.
12	41	HUNDREDS OF CYCLES	POSITION 5	Corresponds to the 500-cps increment in the 7,001,500 F out.
13	40	SYNC	L-3	Observes square trace which should be stationary.
14	40	SYNC	L-2	Observes square trace which should be stationary.
15	40	SYNC	L-1	Observes square trace which should be stationary.
16	40	SYNC	OFF	
17	21, 22	MCS, BAND	TURN TO POSITION 4	Covers 5.75-7.75 band (which contains desired tune-up frequency). CMO's output frequency should be 3,001,500 computed as follows: 7,001,500 less 4,000,000 based on the 4 mc BAND POSITION of control 21.
18	29	OPERATE/CAL	CALIBRATE AT 3,000,000 CHECK POINT	

Table 12-1. —Continued.

Step	Control No.	Control Designation	Operation	Purpose
19	32b 28	LOCK, CAL/BEAT	ADJUST 32b to MAKE 28 BEAT	CMO is calibrated on 3,000,000 (nearest 50 KC check point to 3,001,500 cycles).
20	34, 35	MASTER OSCILLATOR FREQUENCY	SET AT 3,001,500	CMO frequency output is 3,001,500.
21	37	LOCK	LOCK CMO	
22	29	OPERATE/CAL	OPERATE	
23	36	OUTPUT	FULL CLOCKWISE	For good reading on meter 30.
24	33	TUNING KCS	TUNE FOR MAXIMUM ON 30	
25	26 31 32b	SYNC IND ADJ FOR ZERO LOCK	TUNE 32b TO PLACE 31 in CENTER OF SCALE CONCURRENTLY WHILE 26 is lit.	Further detail on this operation is given in CMO manual Part III (B) and in section 4 of Part I dealing with principles of operation of phase detector circuits.
26	32a	LOCK	LOCK	Locks CMO at TUNED FREQUENCY.
27	36	OUTPUT	CLOCKWISE TO PRODUCE	A reading of 30 on meter 30.
28	The CMO is now tuned by steps 17 through 27 and locked.			
29	8	CARRIER LEVEL	FULL CLOCKWISE	Full center frequency output.
30	24	MF TUNING	ADJUST FOR MAX. ON METER 19	Position of 24 should correspond closely with number on control 34.
31	25	OUTPUT	HALF CLOCKWISE	
32	23	OUTPUT TUNING	ADJUST SO THAT 18 DEFECTS TO A POSITION APPROXIMATELY 7,001,500. READJUST SLIGHTLY TO OBTAIN A PEAK READING ON 20	This operation insures tuning on desired frequency and insures correct output frequency and avoids tuning on a parasitic frequency.
33	25	OUTPUT	ADJUST FOR READING OF 9 METER ON 20	Corresponds to one watt.
34	17	SYNC	LIGHTS WHEN TUNED AND SYNTHESIZED	
35	With audio input intelligence, use controls 6 or 10 and gains 7 or 9 to obtain peak of -10 on controls 4 or 5 with TIS input intelligence, use contrqls 6 or 10 out gains 7 or 9 to obtain peaks of -10 on controls 4 or 5. Consult instruction book on TIS-3 operation.			
36	25	OUTPUT	ADJUST FOR READING OF APPROXIMATELY 1 on METER 20	Corresponds to 100 milliwatts.

Table 12-2. —Tuning/Loading Procedure for Main Frame.

STEP	CONTROL NO.	OPERATION	PURPOSE
1	5, 6, 7, 8, 9, 10, 14, 15, 16, 17, 18, 19	Set these 12 tuning devices as per tuning chart to the desired RF output frequency.	To tune first amplifier, second amplifier, IPA, and PA approximately for desired RF output frequency.
2	26, 27	Set PA SCREEN ON/OFF switch (26) and HIGH VOLTAGE circuit breaker (27) to OFF	To make PA inoperative.
3	24, 25	Set TUNE/OPERATE switch to TUNE and ALDC switch to OFF.	To prepare for step 13.
4		Ensure that GPT-10K is connected to an antenna or a dummy load.	To prepare for step 19.
5	20, 3	Set MAIN POWER circuit breaker (20) to ON. Check that AC POWER indicator (3) goes on.	To energize linear amplifiers.
6	11	Turn MULTIMETER switch to RF 1ST AMPL XI.	To measure plate RF voltage.
7	12, 15	Turn the CBE's CARRIER LEVEL switch clockwise as necessary to tune 1ST AMPL plate tank circuit to resonance.	To maximize indication on MULTIMETER (12). (If off scale, reduce exciter's output.)
8	11	Turn MULTIMETER switch to RF IPA EG XI.	To measure grid RF voltage.
9	12, 10	Tune to resonance.	To maximize indication on MULTIMETER (12). (If off scale, reduce exciter's output.)
10		Turn the CBE's CARRIER LEVEL switch fully counterclockwise.	To prepare for steps 11 and 12.
11	21	Depress OVERLOAD RESET pushbutton (21) to place the relays in the relay panel in RESET.	The timer should, by now, have operated to close the interlock circuit.

Table 12-2. —Continued.

STEP	CONTROL NO.	OPERATION	PURPOSE
12a	22, 23, 27	Check that HIGH VOLTAGE circuit breaker (27) is in OFF. Turn INTERLOCK switch (23) to NORMAL. INDICATOR (22) should go on if all interlock circuits are closed.	To check condition of the interlock circuits.
12b	22, 23, 27	If INDICATOR (22) does not go on, turn the INTERLOCK switch counterclockwise to the last position in which the lamp is not on.	To locate position of the switch which causes the interlock circuit to be open.
12c	22, 23, 27	Close the switch which causes the interlock circuit to open. Repeat operations 12a and 12b until INDICATOR (22) goes on when INTERLOCK switch is turned to NORMAL.	To check normalcy of the interlock circuits. The GPT-10K is now ready for high voltage power supply.
13	27, 4	With the PA SCREEN (26) in the OFF position and the TUNE/OPERATE switch (25) in the TUNE position, turn the GPT-10K HIGH VOLTAGE circuit breaker (27) to ON. The PLATE ON indicator (4) and the indicator on the top of the GPT-10K should go on dimly at first but full brightness a second or two later.	The IPA and PA amplifiers now receive full plate voltage, and the IPA amplifier receives half screen voltage (200).
4	13	Turn the CBE's CARRIER LEVEL switch clockwise until some increase is observed on the IPA PLATE CURRENT ammeter (13).	To prepare for step 15.
5	17, 13	Tune the IPA plate tank to resonance by turning IPA TUNING control (17).	To obtain dip on the IPA PLATE CURRENT ammeter (13) indication.
6		Turn the CBE OUTPUT switch counterclockwise.	To prepare for step 18.
7	26	Set PA SCREEN switch (26) to ON.	To prepare for step 19.
8	1	Turn the CBE's CARRIER LEVEL switch clockwise until an increase is observed in the PA PLATE CURRENT meter.	To prepare for step 19.

Table 12-2. —Continued.

STEP	CONTROL NO.	OPERATION	PURPOSE
19	1, 5	Tune the PA plate tank to resonance by turning the PA TUNE knob (5).	To obtain a dip on the PA PLATE CURRENT meter (1) indication.
20		Turn the CBE's CARRIER LEVEL switch fully counterclockwise.	To prepare for loading and retuning the GPT-10K.
21	25, 26, 27	Check that HIGH VOLTAGE circuit breaker (27) is ON, PA SCREEN switch (26) is ON, and set TUNE/OPERATE switch (25) to OPERATE.	The IPA tube is now energized with 400 (screen) and 3000 (plate) voltages. The PA tube is now energized with 1200 (screen) and 7500 (plate) voltages.
22		Repeat operations 6 and 7.	1st amplifier is retuned.
23		Repeat operations 8 and 9.	2nd amplifier is retuned.
24		Repeat operation 15.	IPA is retuned.
25	13, 17, 18, 19, and CBE output	Load the IPA to approximately 275 ma on IPA PLATE CURRENT (13). Use IPA LOADING switch (19), IPA LOADING knob (18), and CBE output as necessary. Simultaneously maintain resonance in the plate tank circuit. (Refer to step 24.) This loading will subsequently be increased as the following RF circuits (step 26a) are tuned to load the antenna.	As IPA LOADING knob (18) is moved in small steps, IPA TUNING knob (17) is moved to dip the IPA PLATE CURRENT meter (13) indication. Hence, the IPA is gradually loaded concurrently with plate tank circuit resonance. Concurrently maintain the IPA grid RF within the limits specified above (40 to 50 volts).
26a	1, 5, 6, 8, 9	The general objective of this step is to load the PA stage to obtain the desired power output, using PA LOAD knob (6), OUTPUT BAL knob (8), and OUTPUT LOADING knob (9) while concurrently maintaining resonance with PA TUNE control knob (5). Power output is indicated by PA output current (in either one of the two antenna meters on top of the GPT-10K), squared, times the output impedance (600 ohms) and is doubled for a PEP reading.	Step 26a assumes balanced GPT-10K operation. In balanced GPT-10K operation, knobs 8 and 9 control the "L" section impedance.

Table 12-2. —Continued.

STEP	CONTROL NO.	OPERATION	PURPOSE
26b	1, 2, 5, 6, 8, 9	The general objective of this step is to load the PA stage to obtain the desired power output, using PA LOAD knob (6), OUTPUT BAL knob (8) and OUTPUT LOADING knob (9) while concurrently maintaining resonance with PA TUNE control knob (5). Power output is indicated by PA OUTPUT meter (2), squared, times the output impedance (72 ohms).	Step 26b assumes unbalanced GPT-10K operation. In unbalanced GPT-10K operation, knobs 8 and 9 control "L" section impedance.
27a		Power output in kw equals the product of the current in one antenna meter (on top of GPT-10K), squared, and multiplied by 0.600 (600-ohm rhombic antenna). This means approximately 3 amp for 5 kw (average) or 10 kw (PEP).	Balanced operation of GPT-10K. An actual antenna at a given frequency may have a resistance value greater or less than 600 ohms.
27b		Power output in kw equals the current in PA OUTPUT meter (2), squared, and multiplied by 0.072 (72-ohm antenna). This means approximately 8 amp for 5 kw (average) or 10 kw (PEP).	Unbalanced operation of GPT-10K. An actual antenna at a given frequency may have a resistance value greater or less than 72 ohms.

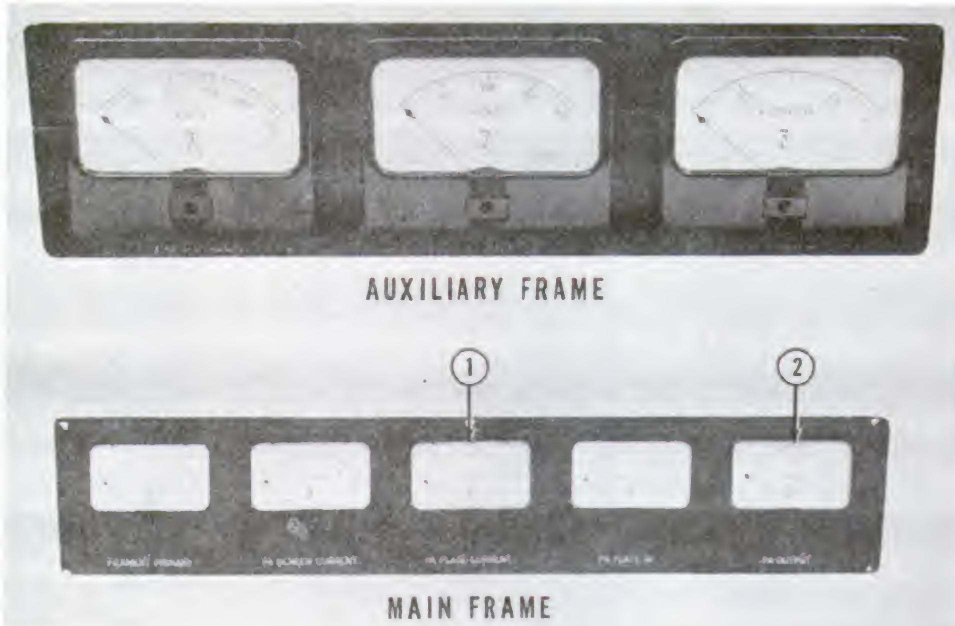


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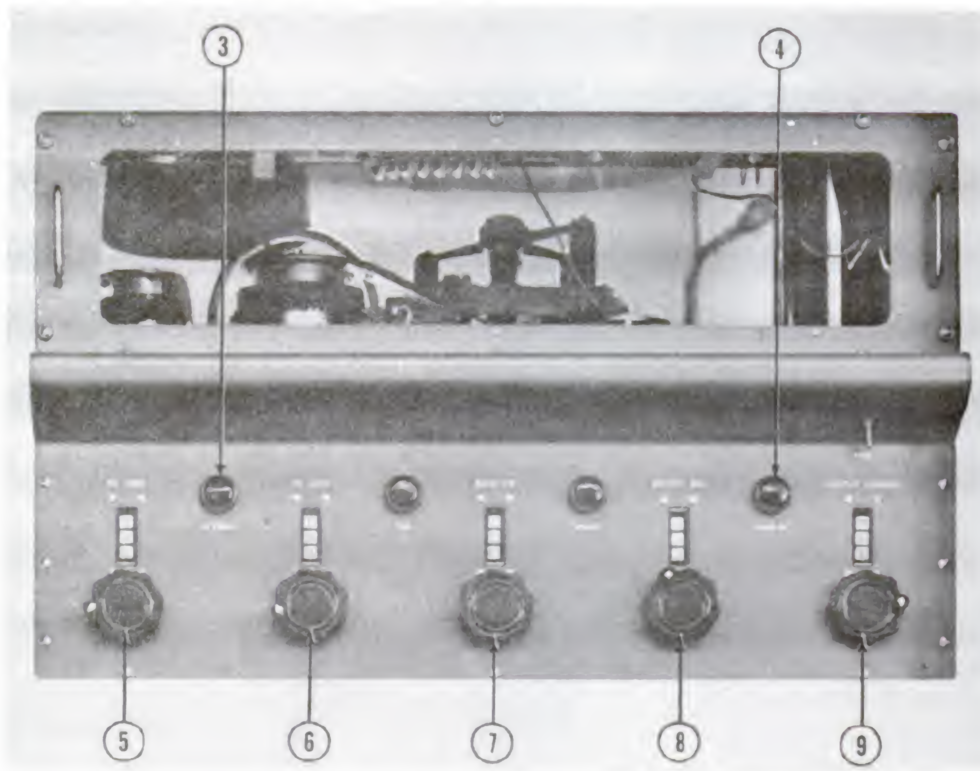
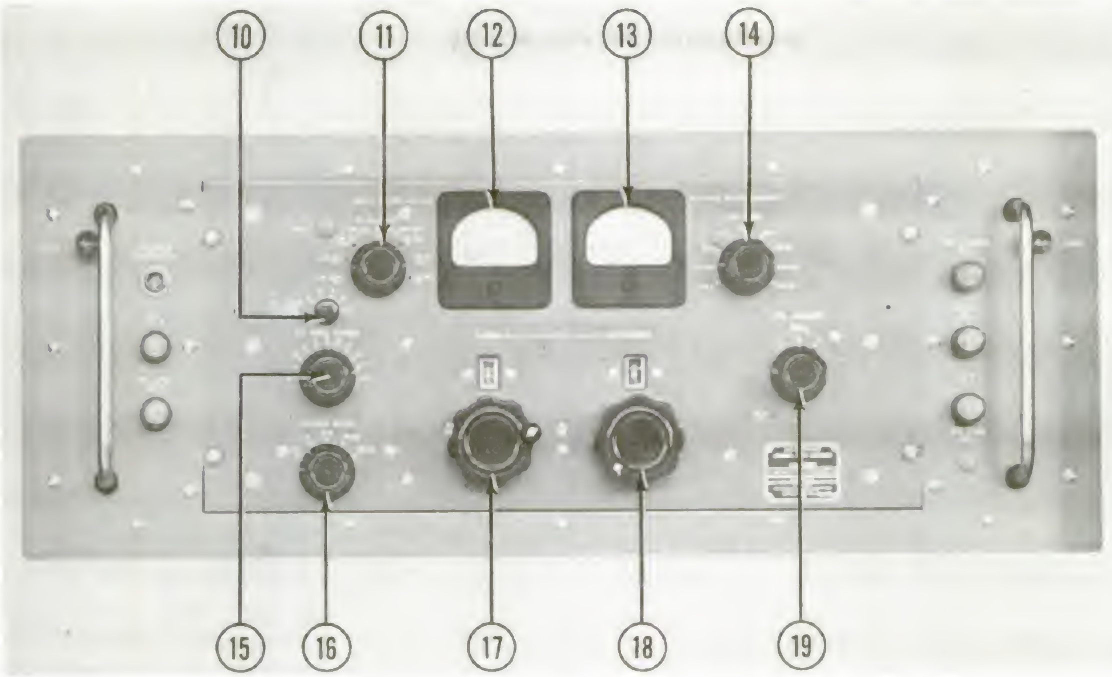
Figure 12-13. —PA Meter Panel.



1.343X
Figure 12-14. —Power Amplifier (PA).



1.344X
Figure 12-15. —RF Amplifier (IPA) (RFC-1).

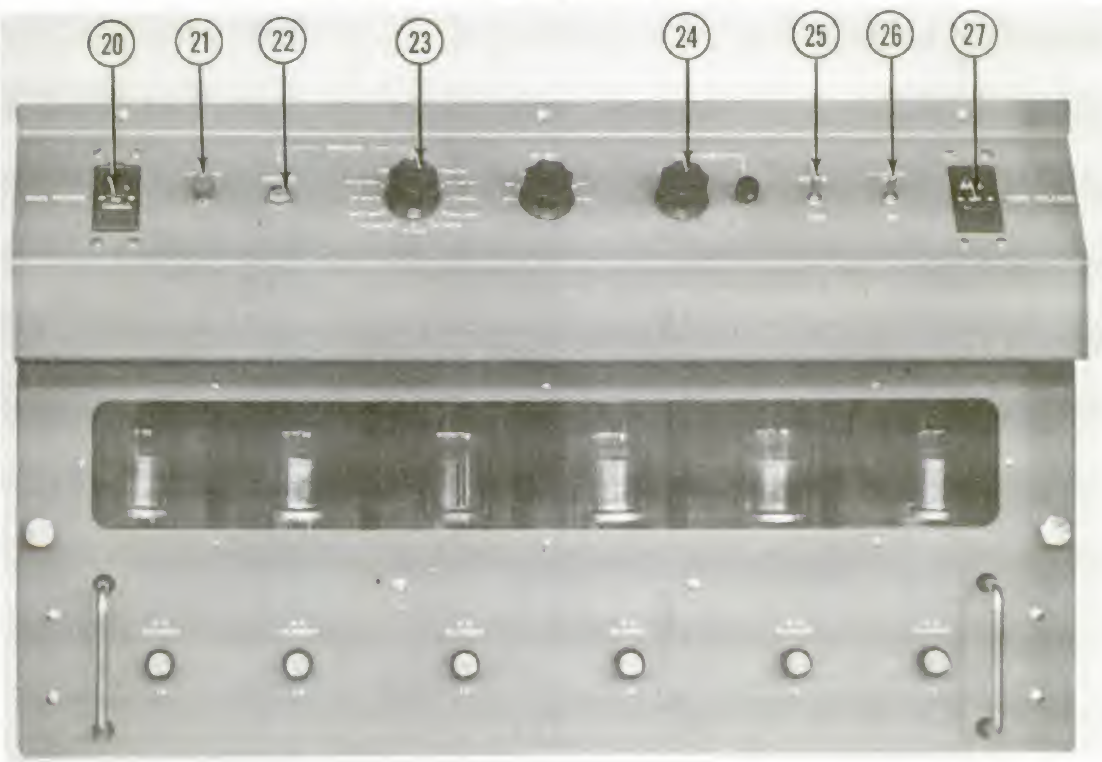


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Figure 12-16. —Main Power Control Panel.

1.346X
Figure 12-17.—Relay and Indicator Control Panels.

CHAPTER 13

COMMON OPERATING ADJUSTMENT OF RADIO RECEIVERS

The following sections describe the operating adjustments of two typical radio receivers. There are many different receivers which the CT M may install and maintain but the equipments described are two of the receivers the CT M is most likely to encounter.

RADIO RECEIVER R-390A/URR

Model R-390A/URR (fig. 13-1) is a high-performance, exceptionally stable, general-purpose radio receiver used aboard ship and at shore stations throughout the Navy. It provides reception of CW, MCW, conventional amplitude-modulated, frequency-shift RATT and FAX, and single-sideband signals within a frequency range of 0.5 to 32 mc. The receiver is a superheterodyne type with multiple frequency conversion. Double conversion is used when the receiver operates from 8 to 32 mc and triple conversion from 0.5 to 8 mc.

Tuning is accomplished by the insertion of powdered-iron cores into the r-f and variable i-f coils at a rate controlled by a complex mechanical arrangement of gears, shafts, and cams. The frequency is indicated by a

34.15

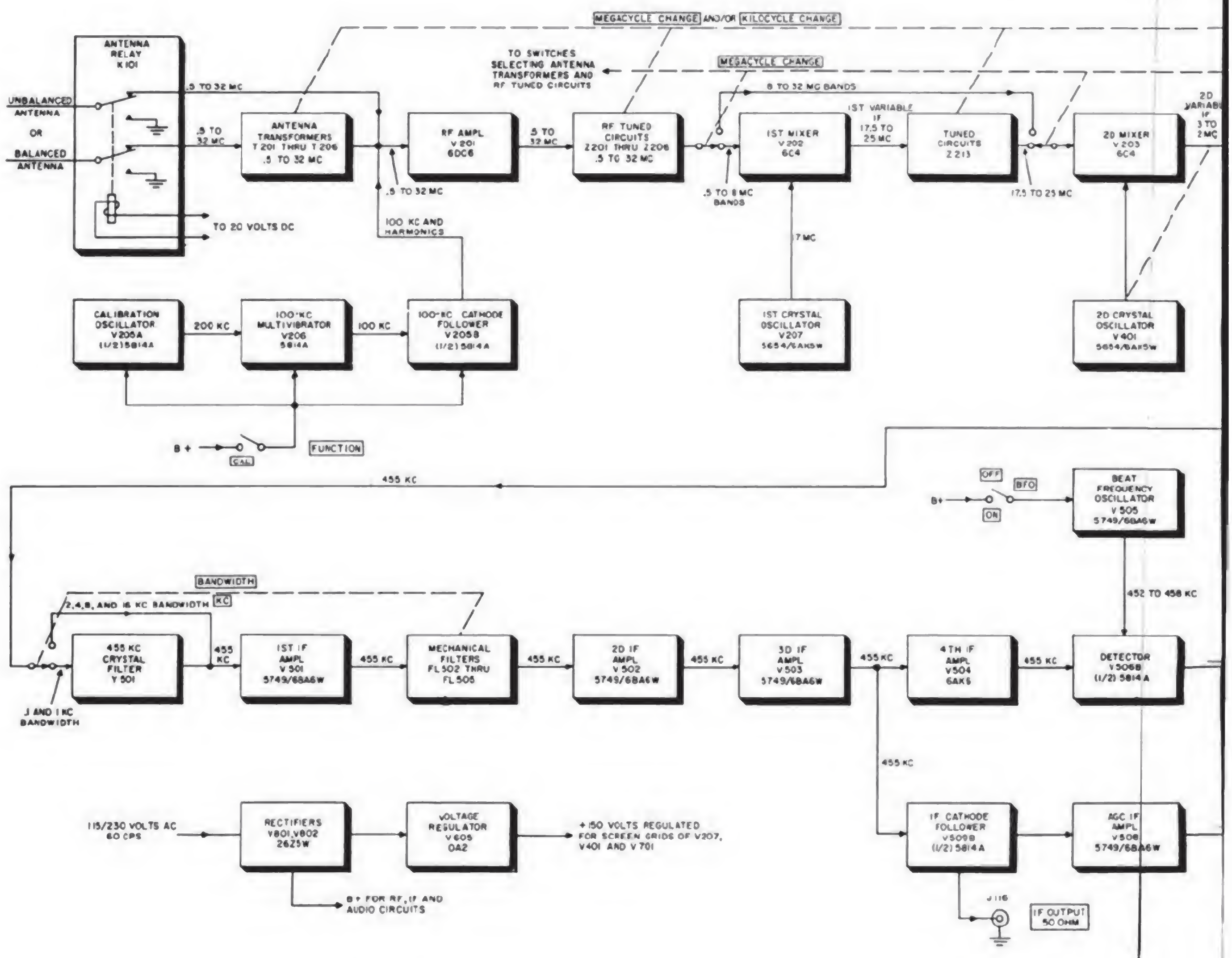
Figure 13-1.—Radio Receiver, R-390A/URR.

counter-type indicator that is accurate to within 300 cps, an accuracy that permits use of the receiver as an accurate frequency meter.

RECEIVER BLOCK DIAGRAM

Figure 13-2 shows the path of the receiver signals from the antenna input to the audio output and i-f output.

Radiofrequency signals are fed into the receiver by either a balanced two-wire antenna such as a doublet, or an unbalanced antenna such as a whip or long wire. Antenna relay K101 disconnects and grounds the antenna during standby, calibration, or break-in operation. When K101 is not energized, the balanced antenna is connected to the input of one of the antenna transformers, T201 through T206, which is selected by the megacycle change switch. The transformers are tuned by the megacycle change and the kilocycle change tuning controls. The output of these tuned circuits is fed into r-f



amplifier V201. If an unbalanced antenna is used, the signal is fed directly to the grid circuit of the r-f amplifier.

The calibration circuit, consisting of 200-kc crystal calibration oscillator V205A, 100-kc multivibrator V206, and 100-kc cathode follower V205B, injects 100-kc markers into the input circuit of r-f amplifier V201. When the function switch is in the CAL position, B+ is connected to the calibration circuit.

Radiofrequency amplifier V201 amplifies the signals from the antenna before they are fed to first mixer V202. Six tuned circuits are selected by a switch that is connected to the megacycle change control. The tuned circuits are adjusted by the kilocycle change and megacycle change controls. The frequency range of tuned circuits Z201 through Z206 is 0.5 to 32 mc.

Signals from 0.5 to 8 mc are coupled from r-f amplifier V201 and fed into the input circuit of first mixer V202. The 8- to 32-mc signals from V201 are switched around the first mixer and fed directly into second mixer V203. When

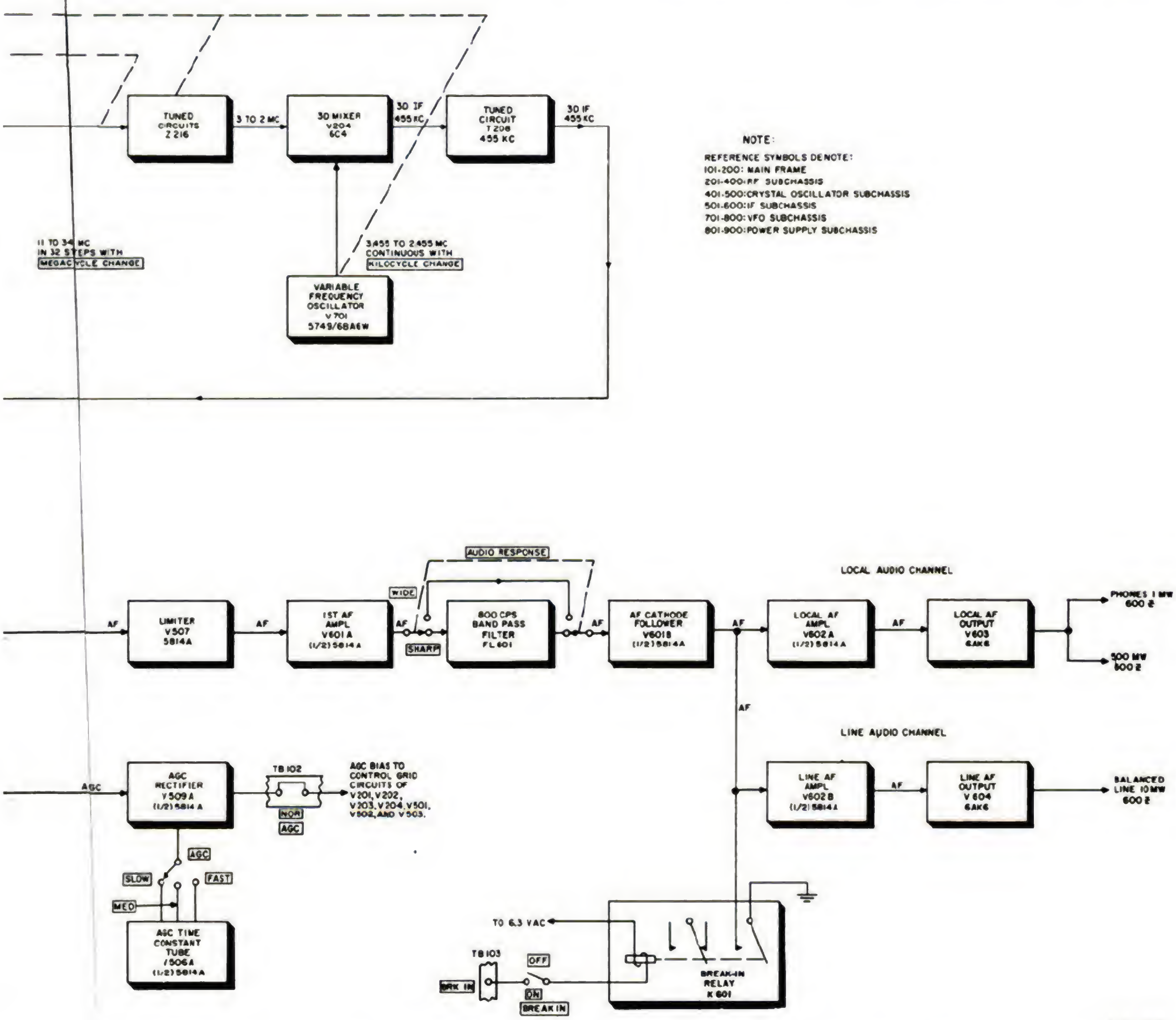


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Figure 13-2.—Block diagram of Radio Receiver, R-390A/URR.

the receiver is operated between 0.5 and 8 mc, the first mixer combines the r-f signals with a 17-mc signal from first crystal oscillator V207. The output (sum) frequency is the first variable i-f signal, and its frequency varies from 17.5 to 25 mc. Tuned circuit Z213 is a triple-tuned device that is permeability tuned as the megacycle change and the kilocycle change controls are operated.

The 17.5- to 25-mc output of the first mixer stage (when the receiver is tuned from 0.5 to 8 mc) or the 8- to 32-mc output from r-f amplifier V201 (when the receiver is tuned from 8 to 32 mc) is selected by the operation of the megacycle change control and fed into second mixer V203. Also fed into V203 is a signal from crystal oscillator V401. The output frequency of V401 is changed as the megacycle change control is operated so that the difference between signal frequency and oscillator frequency is always between 2 and 3 mc. When the frequency reading on the receiver dial is between 0.5 and 0.999 mc, V401 feeds a 20-mc signal into V203. The output frequency of V203 thus varies downward from 3 to 2 mc, except on the 0.5- and 1-mc band, where the output frequency of V203 varies between 2.5 and 2 mc. This is the second variable i-f signal. Another set of triple-tuned coils, Z216, tunes the output of V203 as the kilocycle change control is operated.

The 3- to 2-mc output of the second mixer and its tuned output circuit Z216 is fed into the input circuit of third mixer V204. This stage beats the 3- to 2-mc signal with a continuously variable signal from variable-frequency oscillator V701. This precision oscillator has accuracy comparable with a frequency standard and is controlled by the kilocycle change control. The output of V204 is a fixed frequency of 455 kc. This is the third i-f.

The 455-ck signal is fed into or around 455-kc crystal filter Y501, as determined by the setting of the bandwidth control. When this control is in the .1-kc or 1-kc position, the 455-kc signal is fed through crystal filter Y501, and in any other position it is bypassed around the filter directly to first i-f amplifier V501. The output of V501 is fed into one of four mechanical filters. The output from the selected filter is fed successively through the second, third, and fourth i-f amplifiers (V502, V503, and V504, respectively).

The output of the fourth i-f amplifier, V504, is fed into half-wave diode detector V506B and audiofrequency voltage is produced. This a-f signal is fed to the limiter stage V507, which clips off noise peaks that might render reception difficult.

Beat-frequency oscillator V505 generates and feeds signals variable in frequency from 452 to 458 kc to detector stage V506B. The resultant beat frequency is adjustable continuously from zero to 3000 cps whether the bfo is above or below the carrier signal. Setting the bfo switch to the ON position turns on the bfo.

The audio output from limiter V507 is fed to the first a-f amplifier V601A. This stage amplifies the audio signal and passes it through or around 800-cps bandpass filter FL601, depending upon the setting of the audio response switch. The audio signal is then fed to a-f cathode follower V601B. This stage feeds the audio signals to the local and line audio channels. The local audio channel consists of local a-f amplifier V602A and local a-f output tube V603. This audio source is used for 600-ohm headsets or loudspeakers. The line audio channel is similar to the local audio channel, consisting of line a-f amplifier V602B and line a-f output tube V604. The output provided matches a balanced 600-ohm line.

Intermediate-frequency signals (455 kc) present at the input to fourth i-f amplifier V504 are also fed to the input of i-f cathode follower V509B. This stage provides a 50-ohm source of 455-kc signals for use with a frequency-shift converter for RATT operation. The i-f output connector for this type of service is located on the rear panel of the receiver. Tube V509B also feeds 455-kc signals into the AGC circuit. The first tube of this circuit is AGC i-f amplifier V508. This stage amplifies the 455-kc signal and feeds it to AGC rectifier V509A. The rectifier stage rectifies the i-f signal into direct current, with amplitude in proportion to the average amplitude of the i-f signal. This AGC bias is fed to the control grid circuits of V201 through V204 and V501 through V503. Tube V506A provides AGC time constants of various durations when the AGC switch is set to various positions.

The B+ supply for the receiver is powered by a source of 115 or 230 volts a-c at 60 cps. This a-c power is changed into d-c by rectifiers V801 and V802. A source of regulated 150 volts is provided by voltage regulator V605. This regulated voltage is used as a screen grid supply for V207, V401, and V701.

RECEIVER CONTROLS

The front panel of an R-390A/URR receiver is shown in figure 13-3. Although controls on other receivers may vary somewhat in their placement, appearance, and perhaps in their nomenclature, their basic function will be the same as those on the R-390A/URR.

Function Switch

The FUNCTION SWITCH, which serves several purposes, has a number of positions, each of which will be discussed. The OFF position, which is self-explanatory, simply turns off power to the receiver.

STAND BY.—When the function switch is in the STAND BY position, the filament supply voltages are energized, but the plate supply voltages are not applied to the tubes. This condition readies the receiver for instant use without a long warmup time.

AGC AND MGC.—The abbreviation AGC stands for Automatic Gain Control. When the function switch is placed in the AGC position, the circuitry which automatically adjusts the r-f and i-f amplifier gain to compensate for variations in the level of the incoming signal is activiated. In connection with the AGC function, notice the AGC switch at the top of the panel which has three positions marked SLOW, MEDIUM, and FAST. This AGC switch adjusts the rate at which the AGC circuitry responds to a change in the signal level. The correct position of the AGC switch depends on the type of signal being received.

The abbreviation MGC, which identifies the next position of the function switch, stands for Manual Gain Control. When the function switch is in the MGC position, the AGC circuitry is not activated, and the gain is controlled manually by means of the r-f gain control.

CAL.—When the function switch is in the CAL (calibrate) position, a stable crystal oscillator introduces a signal at the input circuitry of the receiver. This signal allows the operator to calibrate his receiver; that is, to ascertain that the reading of the tuning dial corresponds to the frequency being received. The calibration circuitry of the G-390A permits the operator to calibrate the receiver at each 100-kc point throughout the tuning range of the receiver.

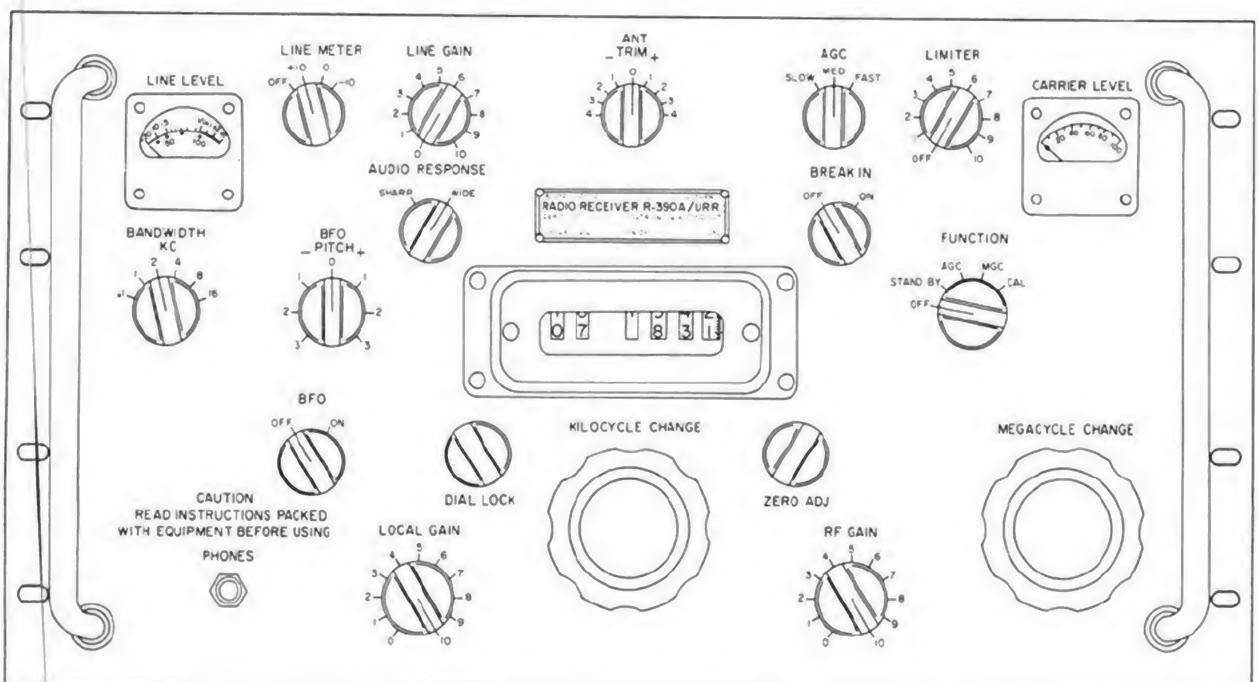

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Figure 13-3.—Front Panel.

In connection with calibration, notice the ZERO ADJ knob near the frequency dial. When turned clockwise, this knob disengages the frequency indicator from the tuning control (KILOCYCLE CHANGE). The calibration procedure consists essentially of the following steps:

1. Tune the receiver to a point where the frequency indicator dial shows an exact multiple of 100 kc.
2. Turn the ZERO ADJ knob clockwise to disengage the tuning controls from the frequency indicator.
3. With the function switch in the CAL position, turn the KILOCYCLE CHANGE control to give the maximum response to the calibration signal.
4. Turn the ZERO ADJ knob counterclockwise to reengage the tuning control to the frequency indicator.

SQUELCH.—In some receivers, the function switch has a SQUELCH position. When the function switch is placed in the SQUELCH position, a circuit is activated which silences the audio portion of the receiver unless the incoming signal is of a predetermined level. One use of this circuit is to relieve the operator, who is monitoring an intermittent by normally strong transmission, from listening to the static and interference in his headphones unless the transmitting station is actually on the air.

Tuning Controls

Two front panel knobs provide the tuning control of the R-390A, the MEGACYCLE CHANGE knob and the KILOCYCLE CHANGE knob. The MEGACYCLE CHANGE knob selects any 1-mc bandwidth of the tuning range. Turning this knob changes the reading of the first two digits of the frequency indicator. The KILOCYCLE CHANGE knob tunes the receiver to any desired frequency within the megacycle band selected by the MEGACYCLE CHANGE control. The last three digits of the frequency indicator dial provide the kilocycle reading. The tuning controls actually adjust the tuned circuits in the r-f stages and in the local oscillator in order to select the desired station frequency and to provide simultaneously the desired i-f signal to the i-f portion of the receiver. The DIAL LOCK knob is associated with the tuning controls. This knob locks the KILOCYCLE CHANGE control so that the frequency setting will not be accidentally changed.

Bandwidth Control

Some transmissions use narrower bandwidths in the r-f spectrum than others. Therefore, receivers are provided with a control which allows the operator to adjust the pass band of the receiver so that only the desired bandwidth is received. On the R-390A receiver, this control is achieved by the BANDWIDTH KC switch, which adjusts the tuned circuits of the i-f portion of the receiver, thereby controlling receiver selectivity. Proper adjustment of this control helps to eliminate noise and interfering signals. Of course, if the bandwidth is set too narrow, part of the incoming signal will be lost.

Beat Frequency Oscillator

Some radio transmissions, such as Morse telegraphy and FSK teletype, contain no audiofrequency information when they are received. If it is necessary or desirable to produce an audio output, some method must be provided to convert the incoming r-f signal to an a-f signal. This requirement is fulfilled by the beat frequency oscillator (bfo). In a superheterodyne receiver, the bfo is installed in such a manner that, when activated, the signal produced by the bfo heterodynes with the i-f signal, producing an audio frequency output signal. On the R-390A, the bfo is activated by the BFO ON-OFF switch, and the pitch of the audio output can be adjusted by the BFO PITCH knob.

Gain Control

The R-390A has three front panel gain controls. The RF GAIN control, which was mentioned earlier, permits manual adjustment of the gain of the r-f and i-f portions of the receiver. The LOCAL GAIN and LINE GAIN knobs control the gain of the audio circuitry. The LOCAL GAIN control adjusts the level of the output to the phone jack. The LINE GAIN controls the level of the audio output used to operate terminal equipment.

Antenna Trimmer

The front panel control labeled ANT TRIM adjusts the input circuit in such a manner that optimum coupling from the antenna to the receiver can be achieved at each frequency.

Audio Response

The AUDIO RESPONSE control, which adjusts the bandwidth of the audio circuits, has two settings, SHARP, and WIDE. The setting of this control will depend on the type of signal being received.

Limiter

When the control labeled LIMITER is activated, the operator can control the amplitude of the audio output circuits to predetermined limits. The setting of the limiter control is dependent upon the type of signals being received; for example, a low setting of the control may be desirable to prevent loud crashes of static in the output when monitoring voice signals. Or, if the received signal is FSK-modulated, it may be desirable to remove all amplitude variations by using a high setting on the LIMITER control. However, for many types of reception, the LIMITER should not be activated.

Break In

The ON-OFF switch labeled BREAK IN is used when a receiver and transmitter are used together as a radio set. When in the On position, circuits are activated which will remove the antenna from the receiver and ground the antenna and receiver audio circuits whenever the transmitter is energized.

Indicators

The R-390A has three indicators on the front panel. The frequency indicator dial indicates the frequency to which the receiver is tuned. This dial is of the digital-counter type which permits the frequency to be read directly with little chance of misreading.

The CARRIER LEVEL indicator is a meter which measures the level of the r-f signal appearing at the input of the receiver. The operator will find this meter valuable in tuning to the exact frequency which will give the strongest signal. It is also used to indicate proper adjustment of the antenna trimmer.

The indicator labeled LINE LEVEL is a meter which may be used to monitor the level of the line audio output used to drive terminal equipment. This meter is placed across the output circuit by the LINE METER switch. The three available values of meter sensitivity (voltage required for full-scale deflection) are determined by the setting of the LINE METER switch. This meter is valuable in maintaining the proper output level when making tape recordings.

RECEIVER REAR PANEL

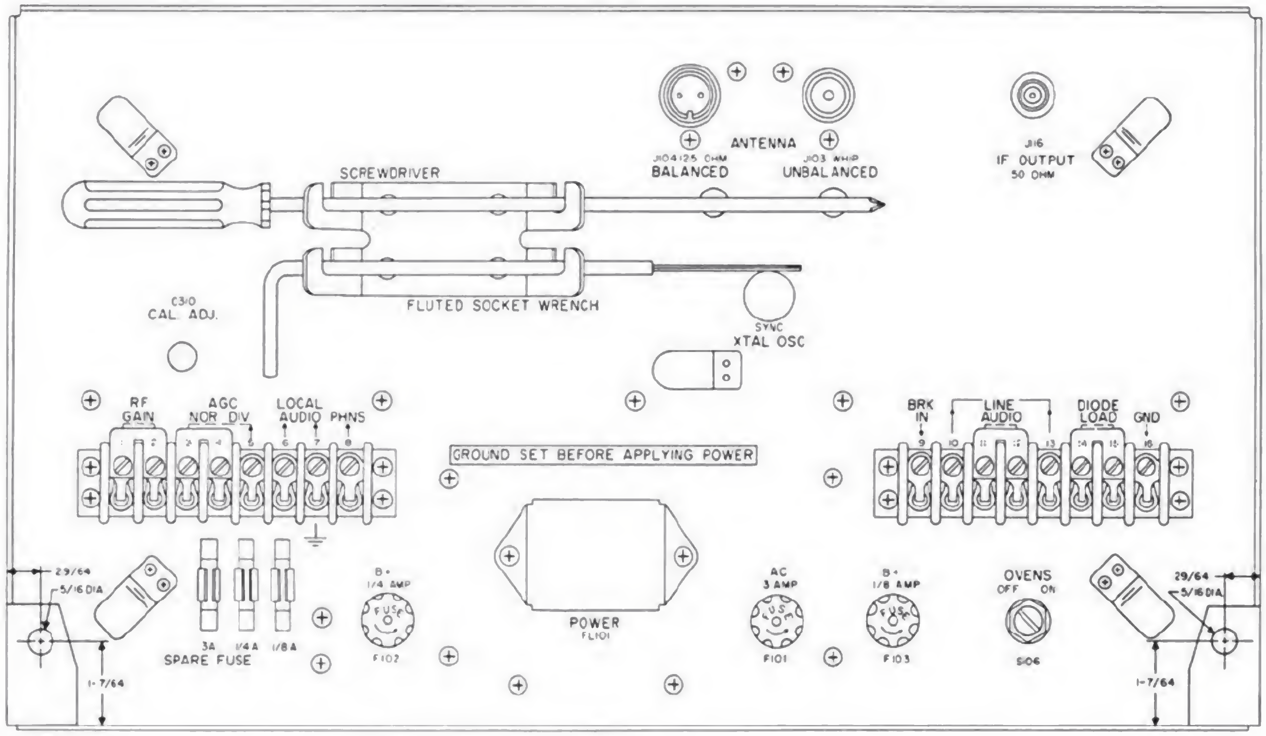
The rear panel of an R-390A/URR receiver is shown in figure 13-4. Various connectors, terminals, fuses, and tools are illustrated along with their appropriate function labels. Note that holders are provided for storage of spare fuses.

DIVERISTY RADIO RECEIVER
AN/FRR-60(V)

The AN/FRR-60(V) (figure 13-5) is a general purpose Diversity Radio Receiver system designed to cover the radio frequency range of 2 to 32 mc. The equipment is capable of reception in the following modes of operation:

(1) SSB (suppressed carrier)
(2) SSB (with carrier)
(3) DSB (suppressed cajrier)
(4) DSB (with carrier)
(5) FSK
(6) FAX
(7) CW
(8) MCW
(9) Pulse modulation
(10) Phase modulation

The 2 to 32 mc range covered by the AN/FRR-60(V) is divided into eight continuous bands. Continuous coverage is provided in either synthesized (controlling the receiver VFO with an external frequency standard) or non-synthesized type of operation. In the synthesized type of operation a frequency standard output is provided over the entire frequency range of the receiver in 100 cycle steps. One complete AN/FRR-60 by itself can only be operated in nondiversity; however, when two complete AN/FRR-60's are operated together and their AGC lines are interconnected, the equipment may be operated in either space-diversity or frequency-diversity. In space-diversity operation the two receiver antenna inputs are connected to separate antennas which are spaced several wavelengths apart. In frequency-diversity operation the two receiver antenna inputs are connected to the same antenna but, the two receivers are operated on



1.347

Figure 13-4.—Rear Panel.

separate frequencies which are being transmitted simultaneously with identical intelligence. Both types of diversity operation are designed to overcome the difficulties encountered in long-range communications which are due to fading. (See chapter 10.)

The AN/FRR-60(V) comprises various modular units mounted in a single rack, and is used in fixed-station or mobile communications systems.

The receiver is capable of receiving input signal variations of 70db without the use of AGC and signal variations of 100db with the use of AGC. These variations will not affect the usability of receivers output signal. Further, the receiver will continue to provide a useable output signal over a dynamic range of 150db. Front panel controls are provided so as the AGC voltage can be adjusted to cope with various signal conditions.

Front-panel meters are provided on the receiver to facilitate the monitoring of r-f input signals, audio output signals, automatic frequency control, drift, carrier level, i-f output, and locking of the synthesizer frequency with the HFO of the Continuous RF Tuner.

An internally generated low-level r-f alignment signal which is provided by the synthesizer, facilitates accurate and rapid tuning of the complete system in the absence of any received radio signal. The locally-generated signal is also useable as a maintenance tool for checking the alignment of the AN/FRR-60(V).

A forced-air cooling system using electric blowers is incorporated within the equipment cabinet. Washable air filters are used to filter out external dust.

DESCRIPTION OF SUB-UNITS

The following paragraphs give a brief description of the subunits used in the AN/FRR-60 (V). Refer to figure 13-6 for subunit relationships and signal flow from antenna input to terminal output. (See foldout for fig. 13-6.)

Continuous RF Tuner TN-376/UR

The Continuous RF Tuner provides for frequency coverage from 2 to 32 mc in eight

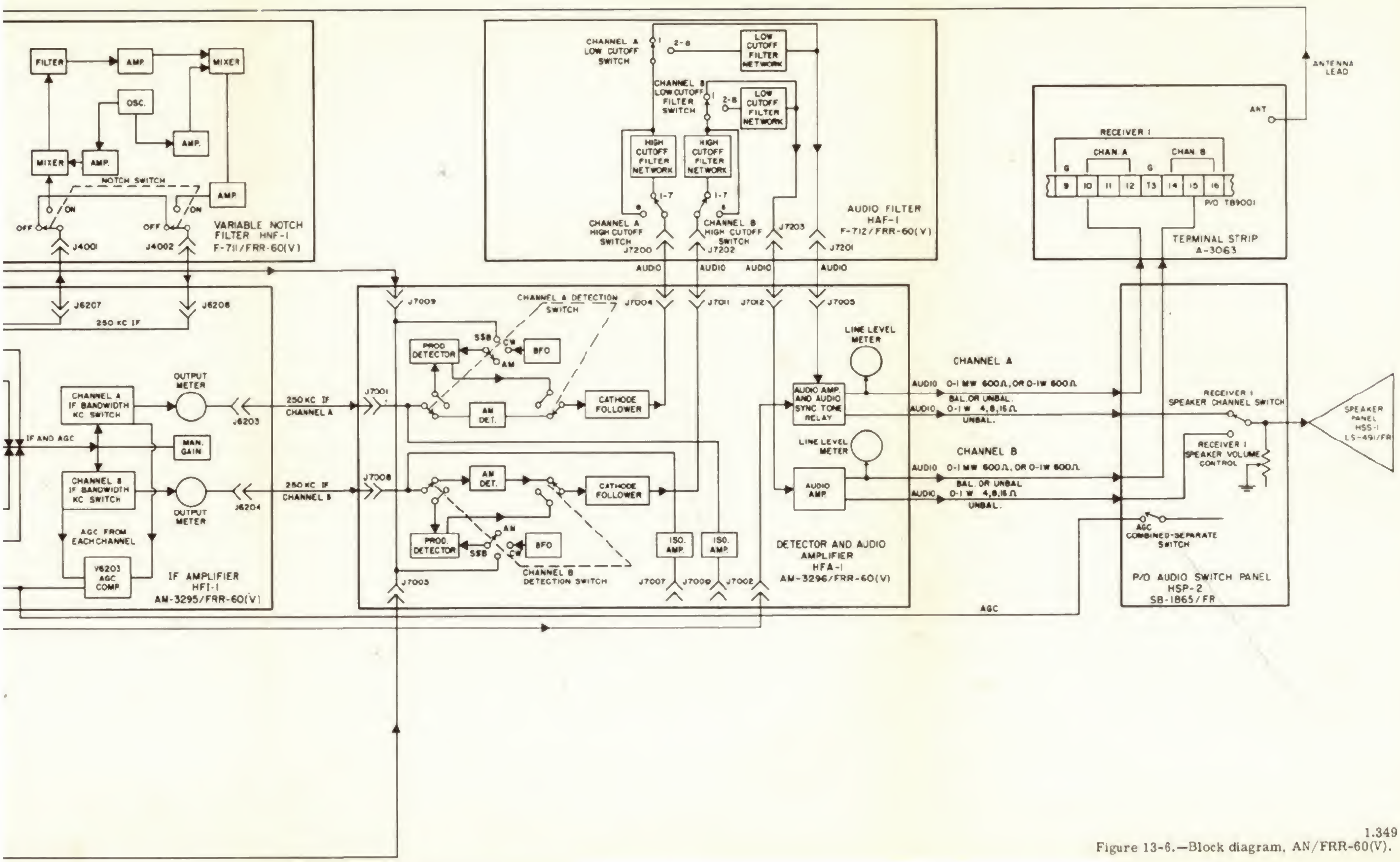


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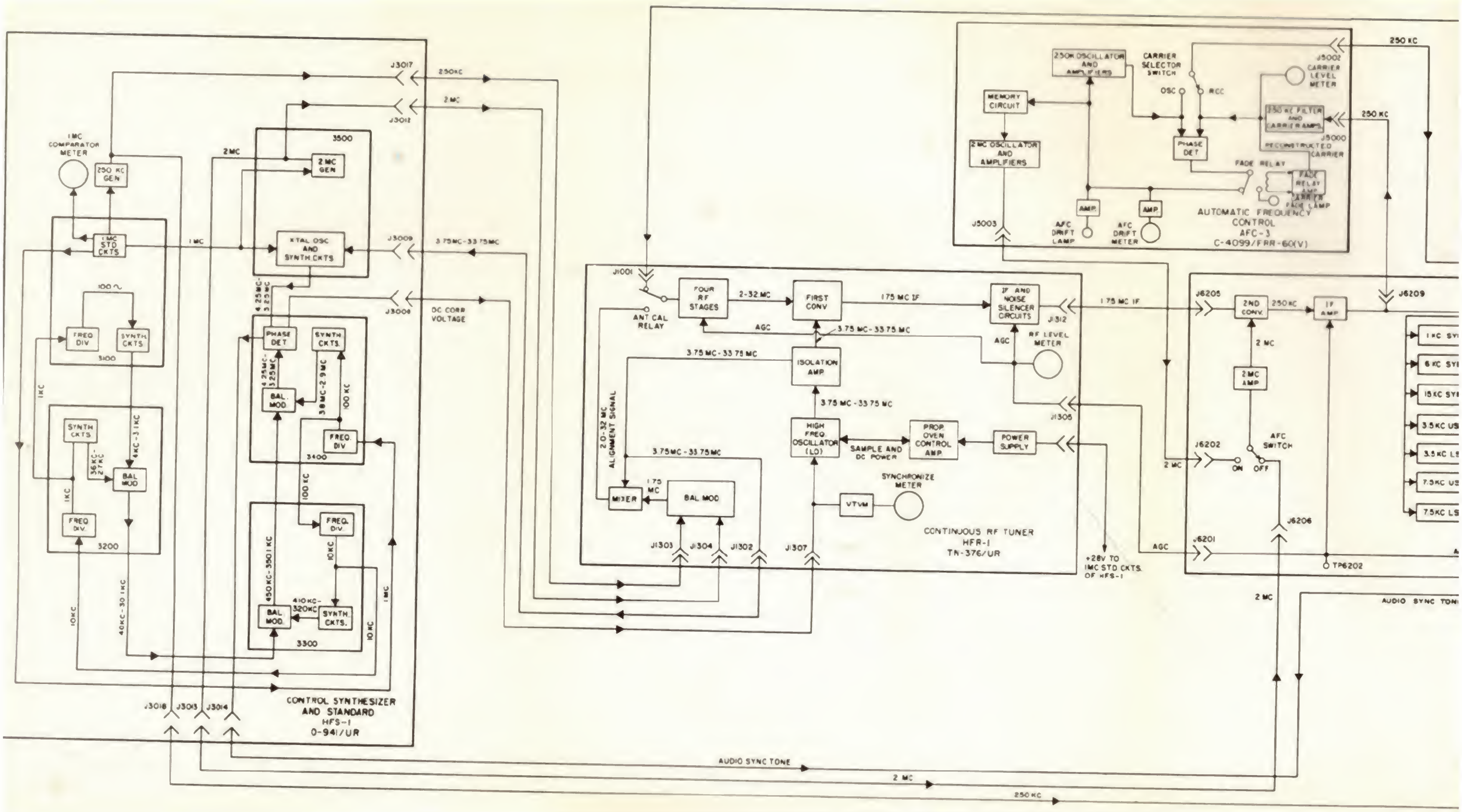
Figure 13-6.—Block diagram, AN/FRR-60(V).


1MC COMPARATOR METER
250 KC GEN
1MC STD CKTS
1MC
100~
FREQ DIV
SYNTH CKTS
3100
1KC
SYNTH CKTS
36KC-27KC
BAL MOD
4KC-3.1KC
FREQ DIV
3200
10KC
40KC-30.1KC
2MC
3500
2MC GEN
XTAL OSC AND SYNTH CKTS
4.25MC-3.25MC
PHASE DET.
SYNTH. CKTS.
BAL. MOD.
3.8MC-2.9MC
100KC
FREQ. DIV.
3400
100KC
10KC
450KC-350.1KC
410KC-320KC
3300
1MC
J3017
250KC
J3012
2MC
J3009
3.75MC-33.75MC
J3006
DC CORR VOLTAGE
CONTROL SYNTHESIZER AND STANDARD HFS-1 O-941/UR
J3018
J3013
J3014
AUDIO SYNC TONE
2 MC
250KC
J1001
ANT CAL RELAY
FOUR RF STAGES
2-32 MC
FIRST CONV
1.75 MC IF
IF AND NOISE SILENCER CIRCUITS
J1312
AGC
3.75 MC-33.75 MC
ISOLATION AMP
RF LEVEL METER
2.0-32 MC ALIGNMENT SIGNAL
HIGH FREQ. OSCILLATOR (LO)
SAMPLE AND DC POWER
PROP OVEN CONTROL AMP.
POWER SUPPLY
J1305
MIXER
1.75 MC
BAL MOD
VTVM
SYNCHRONIZE METER
J1303
J1304
J1302
J1307
CONTINUOUS RF TUNER HFR-1 TN-376/UR
+28V TO 1MC STD CKTS. OF HFS-1
250KC OSCILLATOR AND AMPLIFIERS
CARRIER SELECTOR SWITCH
OSC
RCC
MEMORY CIRCUIT
2MC OSCILLATOR AND AMPLIFIERS
PHASE DET.
250 KC FILTER AND CARRIER AMPS.
J5002
CARRIER LEVEL METER
J5000
RECONSTRUCTED CARRIER
FADE RELAY
FADE RELAY AMP
CARRIER FADE LAMP
AMP.
AFC DRIFT LAMP
AFC DRIFT METER
J5003
AUTOMATIC FREQUENCY CONTROL AFC-3 C-4099/FRR-60(V)
250 KC
J6205
2ND CONV.
IF AMP
J6209
2 MC
2MC AMP
J6202
ON
OFF
AFC SWITCH
J6206
J6201
TP6202

bands and displays the tuned frequency on a 14 inch slide rule type scale. The tuner will accept synthesized control voltage from the synthesizer unit 0-941/UR for extreme frequency accuracy and stability. The RF Tuner converts the input r-f frequency to their lower first i-f of 1.75 mc. The TN-376/UR obtains its operating power from an external power supply unit, PP-3341/FRR-60(V).

Control Synthesizer and Standard 0-941/UR

The Control Synthesizer and Standard monitors the HFO frequency of the Continuous RF Tuner and provides correction voltage to maintain the free-running oscillators in the TN-376/UR to a stability of 1 part in 10^8 in 24 hours. The frequency that is to be synthesized in the TN-376/UR by the Synthesizer unit is displayed on the front panel of the 0-941/UR in 1 inch illuminated numerals. A change of synthesized frequency in 100 cycle increments is accomplished by means of manually controlled detented switches located on the front panel of the equipment. The 0-941/UR obtains its operating power from an external power supply unit, PP-3341/FRR-60(V).

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Figure 13-5.—Diversity Radio Receiver, AN/FRR-60(V).

Automatic Frequency Control Unit C-4099/FRR-60(V)

The Automatic Frequency Control Unit (AFC), accepts a 250 kc input signal from the IF Amplifier Unit, AM-3295/FRR-60(V), and provides automatic frequency control which will compensate for a frequency drift in the received transmission. The AFC unit automatically synchronizes to a received signal within ± 50 cps when the received signal is suppressed as much as 30db at 1 microvolt above noise threshold and will remain synchronized for approximately ± 1,000 cps of drift at a maximum drift rate of 10 cps/second. The C-4099/FRR-60(V) obtains its operating power from an external power supply unit, PP-3341/FRR-60(V).

IF Amplifier AM-3295/FRR-60(V)

The IF Amplifier unit accepts a 1.75 mc input signal from the Continuous RF Tuner, TN-376/UR, processes the input signal through manually controlled selectable bandpass filters, and converts the input signal to 250 kc for further demodulation in the Audio Amplifier, AM-3298/FRR-60(V). Rear panel facilities are provided for connecting the Notch Filter, F-711/FRR-60(V). The AM-3295/FRR-60(V) obtains its operating poser from an external power supply unit, PP-3341/FRR-60(V).

Variable Notch Filter F-711/FRR-60(V)

The Variable Notch Filter accepts a 250 kc input signal from the IF Amplifier and, when used, will attenuate an interfering signal within ±8 kc of the 250 kc input signal. Filtering by the F-711/FRR-60(V) can be engaged or disengaged by means of front-panel controls. Signals from the Variable Notch Filter are returned to the IF Amplifier for the purpose of bandpass filtering. The F-711/FRR-60(V) obtains its operating power from an external power supply unit, PP-3341/FRR-60(V).

Detector and Audio Amplifier AM-3298/FRR-60(V)

The detector and Audio Amplifier unit accepts dual 250 kc input signals from the IF Amplifier unit, demodulates these signals and provides dual audio channel outputs. Facilities are incorporated on the rear panel to channel the output signals to a passive dual audio filter. The AM-3298/FRR-60(V) obtains its operating power from an external power supply unit, PP-3341/FRR-60(V).

Audio Filter F-712/FRR-60(V)

The Audio Filter requires no operating voltages other than the signals fed to it by the Detector and Audio Amplifier, AM-3298/FRR-60(V). The F-712/FRR-60(V) accepts dual audio signals from the audio amplifier and its adjustable by front-panel controls which vary the upper and lower frequency cutoff point of each audio filter to suit operational requirements. Front-panel controls have been engineered to minimize confusion when establishing audio bandpass.

Power Supply PP-3341/FRR-60(V)

The Power Supply provides for regulated B+, regulated bias voltage, and filament voltages for one complete rack of AN/FRR-60(V) units.

Audio Switch Panel SB-1865/FR

The Audio Switch Panel filters and interconnects the two audio output channels (Channels A and B) to a terminal strip for further wire transmission to local or remote terminal equipment such as single-channel or multi-channel teletypewriter converter equipment. The Audio Switch provides front-panel controls to apply Channel A or Channel B audio signals to the loudspeaker, disconnect audio signals from the loudspeaker, adjust the audio level of signals applied to the loudspeaker, and combine or separate the AGC of both receivers when used in diversity/non-diversity.

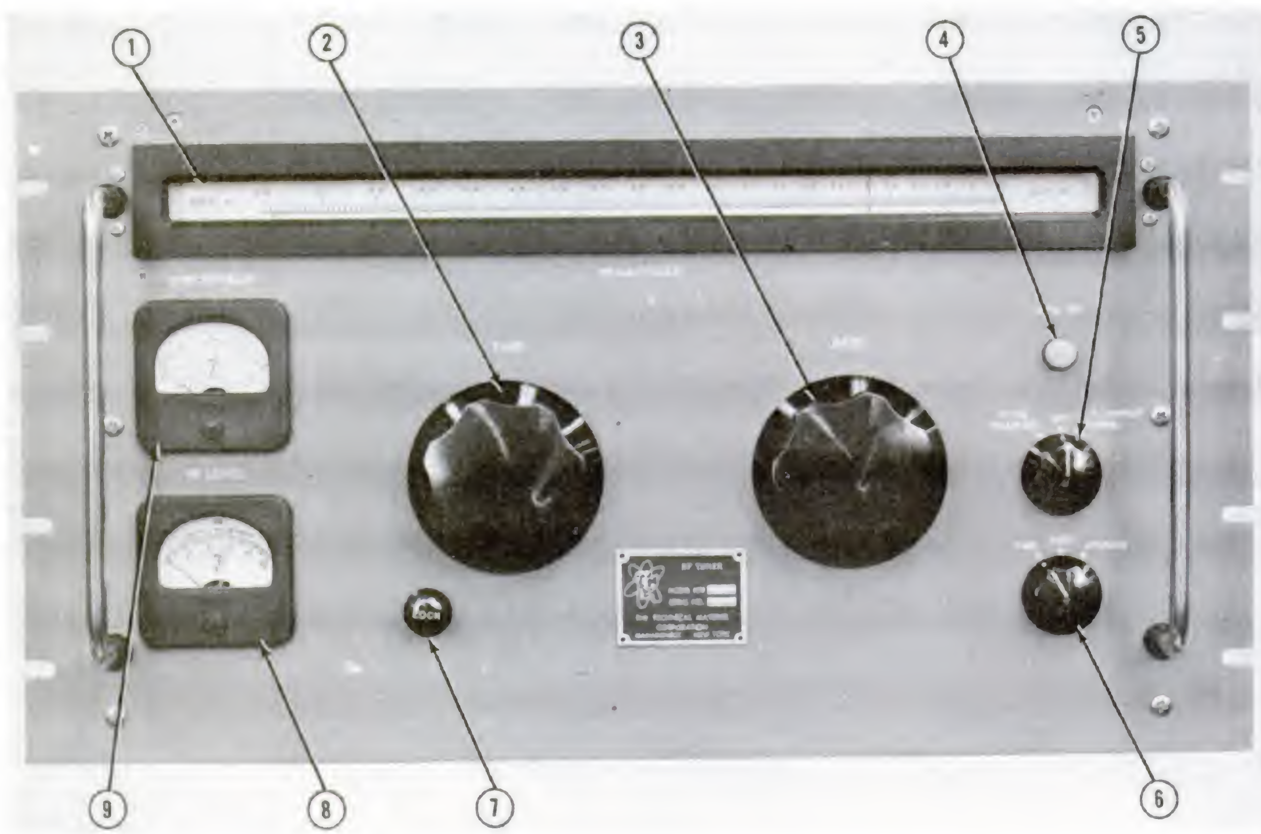
Speaker Panel LS-491/FR

The Speaker Panel houses a single 4-inch permanent-magnet (p-m) speaker that is used to monitor the receiver outputs.

COMMON EXTERNAL ADJUSTMENTS

Continuous RF Tuner TN-376/UR

The front panel controls and instruments of the RF Tuner (see figure 13-7) are arranged to permit ease of tuning through any of the eight r-f bands



1.350X

Figure 13-7.—Continuous RF Tuner, TN-376/UR.

to the desired frequency within the range of 2 to 32 mc, non-synthesized continuous coverage operation or synthesized operation in 100 cycle steps, and alignment and sensitivity checks of the tuner. All operating controls are identified by front panel markings. The following numeral and panel designations list the controls, instruments and the function of each (see figure 13-7).

(1) MEGACYCLES. The megacycle indicator displays the r-f band selected by operation of the band control knob; refer to designation number (3).

(2) TUNE. The tuning knob moves the slide rule pointer along the megacycle indicator to the appropriate frequency desired. This control is fitted with a locking device; refer to designation number (7).

(3) BAND. The band control rotates the illuminated MEGACYCLE indicator to the desired r-f band. The r-f bands are arranged as follows:

BAND	1	2-3 mc
BAND	2	3-4 mc
BAND	3	4-6 mc
BAND	4	6-8 mc
BAND	5	8-12 mc
BAND	6	12-16 mc
BAND	7	16-24 mc
BAND	8	24-32 mc

(4) SYNC IND. The synchronizing indicator lamp lights to indicate that the synthesizer is in synchronization with the HFO in the r-f tuner unit.

(5) NOISE SILENCER/OFF/ALIGNMENT SIGNAL. In the NOISE SILENCER position, this three position control activates the noise silencer circuits; disables the alignment signal generator, and connects the antenna (ANT) input jack to the first r-f amplifier circuit. In the OFF position, the control disables the output of the noise silencer, disables the alignment signal generator, and connects the ANT input jack to the first r-f amplifier circuit. In the ALIGNMENT SIGNAL position the control activates the alignment signal generator, disables the output of the noise silencer, and connects the calibration (CAL) input jack to the first r-f amplifier circuit.

(6) TUNE/SYNC/OPERATE. In the TUNE position, this three position control grounds the d-c correction voltage from the synthesizer unit causing the HFO circuit to run free, and de-energizes the AUDIO SYNC TONE relay of the audio frequency amplifier unit so as to remove the audio sync tone from channel A. In this position the SYNCHRONIZE meter should read zero (center scale). In the SYNC position the control grounds the d-c correction voltage from the synthesizer unit causing the HFO circuit to run free, and energizes the AUDIO SYNC TONE relay of the audio frequency amplifier unit so as to inject an audio sync tone in channel A of the audio amplifier. In the OPERATE position, the control causes the synthesizer circuits to control the HFO circuits for synthesized operation in 100 cycle steps, and de-energizes the AUDIO SYNC TONE relay of the audio amplifier unit so as to remove the audio sync tone from channel A.

(7) LOCK. Locks the tuning control (2) in the desired position.

(8) RF LEVEL. The r-f level meter indicates the strength of the antenna input signal or the alignment signal in db above a reference level of 1 μV.

(9) SYNCHRONIZE. The sync meter indicates the amount and polarity of the d-c voltage required to keep the HFO in sync with the synthesizer output. When the system is out of synchronization, the meter will read zero (center scale). This meter functions only when the Continuous RF Tuner is operating in the synthesized mode of operation.

Control Synthesizer and Standard 0-941/UR

The controls and indicators of the Control Synthesizer and Standard (figure 13-8) are arranged to permit the selection of any frequency from 2 to 32 mc in 100 cycle steps. By rotation of the frequency selector switches the used frequency is indicated by the nixies (solid state or vacuum tube, luminous numerical indicating devices) on the front panel. The following numeral and panel designations lists the controls, instruments and function of each (see figure 13-8).

(1) .1 KC. The .1 KC control tunes the synthesizer in 100 cycle steps.

(2) 1 KC. The 1 KC control tunes the synthesizer in 1,000 cycle steps.

(3) 10 KC. The 10 KC control tunes the synthesizer in 10 kc steps.

(4) 100 KC. The 100 KC control tunes the synthesizer in 100 kc steps.

(5) 1 MC. The 1 MC control tunes the synthesizer in 1 mc steps.

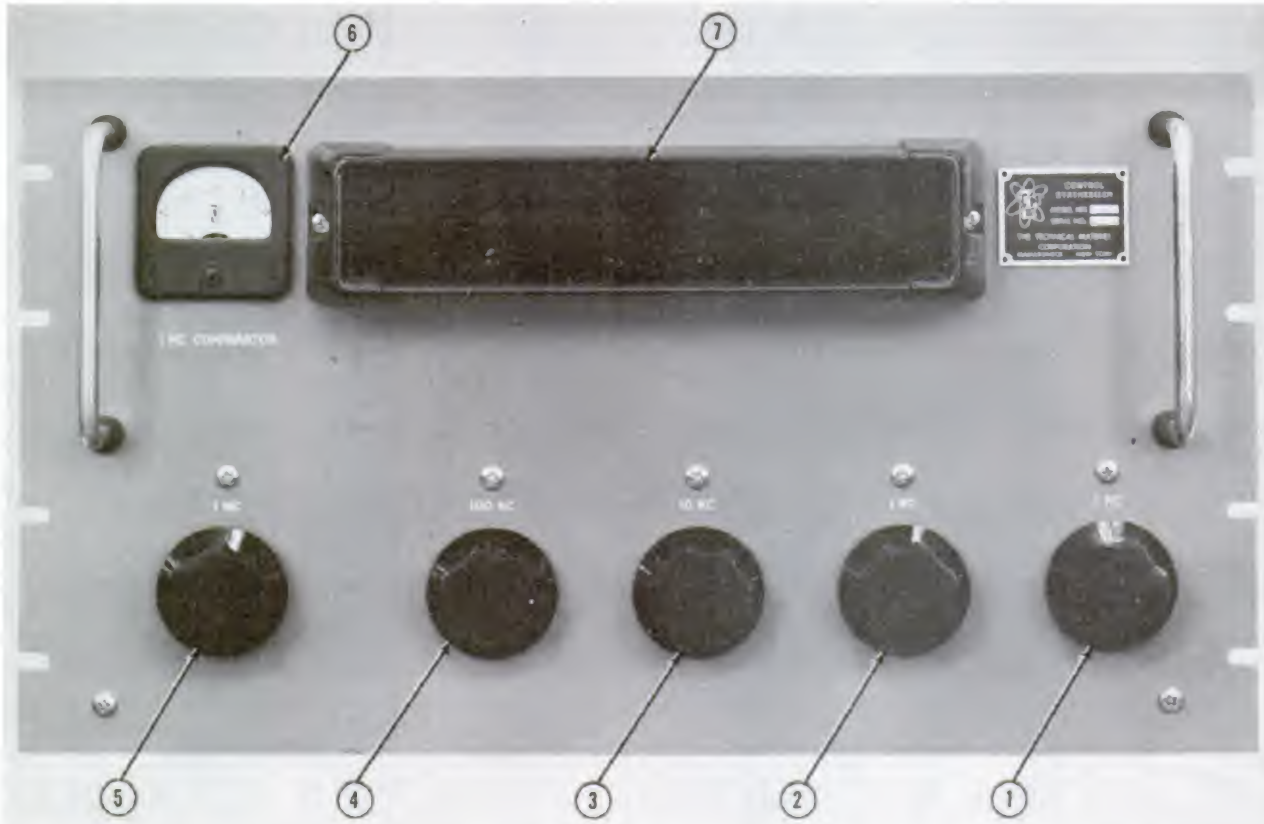


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Figure 13-8.—Control Synthesizer and Standard, 0-941/UR.

(6) 1 MC COMPARATOR. The 1 mc comparator meter indicates the frequency error of the internal 1 mc frequency standard.

(7) NIXIE FREQUENCY INDICATOR. Indicates (using nixie units) the frequency that the equipment is tuned to.

Automatic Frequency Control Unit C-4099/FRR-60(V)

The AFC unit (figure 13-9) is normally operated with the CARRIER selector switch in the OSC position. With the switch in the OSC position, the receiver product detector receives a corrected 250 kc injection frequency from the AFC product detector oscillator. Also, in this position, the AFC responds to correct the carrier drift at the speed rated (10 cps/second maximum): the 250 kc injection frequency will be in phase with the carrier input within 1 cycle (or 360°). In cases where phase is of primary importance, however, it may be elected to place the CARRIER SELECTOR switch in RCC (reconstructed carrier) position. This effectively strips the 250 kc carrier of its sidebands, amplifies the carrier, and feeds this carrier back into the receiver product detector as the injection frequency. The following numeral and panel designations list the controls, instruments and the function of each (see figure 13-9).

(1) DRIFT. The DRIFT meter indicates the total drift of the receiver i-f carrier. A center scale reading indicates zero drift. The meter scale is color coded as follows:

Color	Drift (approx)
Green	500 cps
Yellow	500 cps to 1 kc
Red	1 kc or more

(2) ALARM. The alarm lamp will light when the carrier frequency has drifted off center frequency by more than ±750 cps.

(3) SENSITIVITY. The SENSITIVITY controls the gain of the carrier amplifier stage. The sensitivity may be increased or decreased depending on the ratio of signal to noise.

(4) RESET. The RESET control re-centers the AFC oscillators when the operator is required to tune the receiver to another frequency or resynchronize the receiver due to a drifting signal.

(5) TUNING KCS. The TUNING KCS control tunes the AFC unit's converter injection oscillator to enable the operator to synchronize to the received signal.

(6) CARRIER SELECTOR. The carrier selector control is used to select either the product detector oscillator (OSC) or the reconstructed carrier (RRC) position. The function of both positions is explained in a previous paragraph.

(7) FADE. The FADE lamp will light when the received signal fades below a predetermined level.

(8) LEVEL. The LEVEL meter indicates the strength of the received carrier.

IF Amplifier AM-3295/FRR-60(V)

Ti-f amplifier unit (figure 13-10) is designed to operate with a high degree of versatility. The two i-f channels are identical and the controls for each channel are functionally grouped. By the use of two IF BANDWIDTH KC front switches, either a symmetrical upper or lower sideband may be switched to channel A or B. This type of versatility is helpful, especially during independent sideband operation where voice information may be transmitted on one sideband and multichannel information on the other sideband. When information is transmitted in this manner, sideband orientation of information need not be maintained at the transmitter. The following numerical and panel designations list the controls, instruments and the function of each (see figure 13-10).

(1) and (3) OUTPUT. The OUTPUT meter indicates the output level of the channel.

(2) MANUAL GAIN. The MANUAL GAIN controls the overall gain of the i-f amplifier.

(4) and (8) IF BANDWIDTH KC. The IF BANDWIDTH KC controls the bandpass of the i-f amplifier and selects either the upper or lower sideband in single sideband operation, or both sidebands in double sideband operation.

(5) and (7) AGC DECAY. The AGC DECAY controls the amount of time it takes the AGC to decay after a signal starts to fade.

(6) AFC ON-OFF. The AFC ON-OFF activates or disables the AFC circuits.

Variable Notch Filter F-711/FRR-60(V)

The Variable Notch Filter (figure 13-11) controls are located on the front panel and allow the operator to select an audio filter to tune an unwanted signal into a notch filter for elimination from the desired signal. If an i-f signal exists with no interfering signal, the notch may be turned off. The following numeral and panel designations list the controls and the function of each (see figure 3-11).

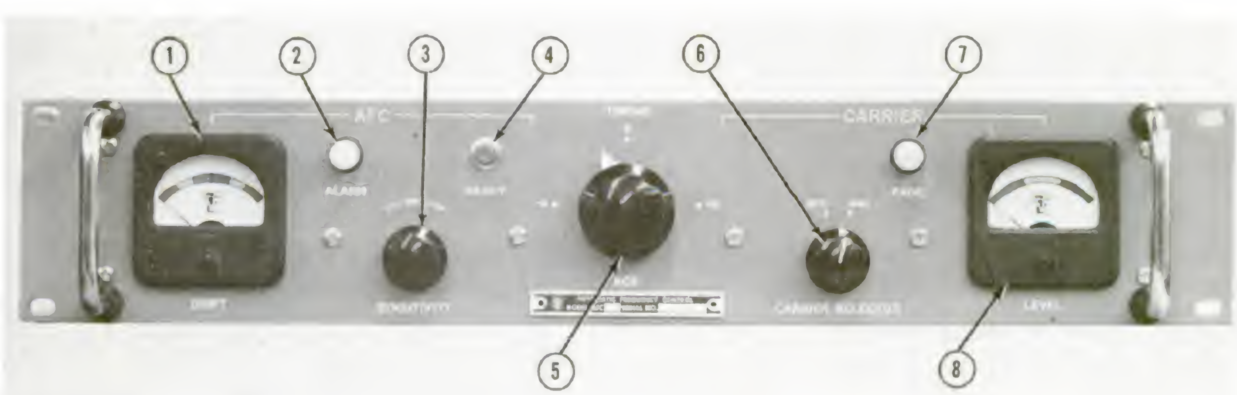

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Figure 13-9.—Automatic Frequency Control, C-4099/FRR-60(V).

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Figure 13-10.—Intermediate Frequency Amplifier, AM/3295/FRR-60(V).

(1) NOTCH ADJUST. The NOTCH ADJUST control is used to vary the center frequency of the notch filter either plus or minus from the center i-f by as much as ±8 kc.

(2) NOTCH OFF-ON. The NOTCH OFF-ON controls the 250 kc i-f input to the filter. In the OFF position the signal bypasses the filter.

Detector and Audio Amplifier AM-3298/FRR-60(V)

The Detector and Audio Amplifier (figure 13-12) is divided into two identical channels (A and B). Each channel has identical controls which are functionally grouped. The following numeral and panel designations list the controls, instruments and the function of each (see figure 13-12).

(1) POWER. The POWER control switch has two positions. The STANDBY position is used to disconnect the operating voltages from the unit. The OPERATE position is used when the equipment is in operation and connects the operating voltages to the unit.

(2) and (8) DETECTION. The DETECTION control selects the mode of detection and is capable of operating in AM, CW, or SSB, depending on the position of the switch.

(3) and (9) BFO. The BFO control is used in the CW position and will vary the bfo ±5 kc (maximum) about the center i-f of 250 kc.

(4) and (10) LINE LEVEL. The LINE LEVEL meter indicates the audio level across the output line.

(5) and (11) LEVEL ADJUST. The LEVEL ADJUST control varies the audio output level across the output line.

(6) and (12) PHONES. The PHONES jack is used to connect a standard head-set to the unit for the purpose of monitoring the output signal.

(7) and (13) MONITOR. The MONITOR control is used to vary the level of the signal in the monitor phone jack headset.

Audio Filter F-712/FRR-60(V)

The Audio Filter (figure 13-13) is used to pass a particular band of frequencies in the audio range for either Channel A or Channel B. An example would be to pass a 2 kc band with the low end of the band starting at .5 kc and ending at the high end with 2.5 kc. Set the low cutoff control to .5 kc and the high cutoff

control to 2.5 kc. As another example, to pass all frequencies above 2.5 kc set the low cutoff control to 2.5 kc and set the high cutoff control to the OUT position. The following numeral and panel designations list the controls and the function of each (see figure 13-13).
(1) and (3) LOW CUTOFF. The control is used to set the low cutoff frequency for the indicated channel. (2) and (4) HIGH CUTOFF. The control is used to set the high cutoff frequency for the indicated channel.

Power Supply PP-3341/FRR-60(V)

The Power Supply (figure 13-14) contains no front panel controls. On the front panel are indicator lamps and indicator fuses. There are also indicator fuses located on the top panel just behind the front panel.

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Figure 13-11.—Variable Notch Filter, F-711/FRR-60(V).

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Figure 13-12. —Detector and Audio Amplifier, AM-3298/FRR-60(V).

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Figure 13-13.—Audio Filter, F-712/FRR-60(V).

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Figure 13-14.—Power Supply, PP-3341/FRR-60(V).

CHAPTER 14

PRINCIPLES OF SINGLE-SIDEBAND COMMUNICATIONS

Because single sideband is becoming increasingly important in Navy applications, it is necessary that Navy technicians acquire an understanding of the basic principles of operation. If the technician understands the principles of operation, he will experience little difficulty in utilizing the instruction books or technical manuals in corrective maintenance work.

It is, of course, not possible to give complete coverage of this subject in one chapter. Some references that will be of value to the CT M are included in Electronics Information Bulletin. The alert technician will make every effort to keep abreast of the advances in the field.

It is the purpose of this chapter to present, first of all, the advantage of single sideband (SSB) and to point out the differences between SSB and the conventional system of amplitude-modulation communications utilizing both sidebands and the carrier. Next, some of the important problems in SSB communications are discussed.

Following this is a discussion of the various methods of single-sideband generation and the commonly used types of filters and linear amplifiers.

In order to approach the subject of equipment operation in the simplest and most logical manner, a functional block diagram of a widely used single-sideband transceiver is given first. The diagram is accompanied by a discussion of the functions performed in each of the blocks.

A simplified circuit diagram of the equipment is included next. The various circuits are analyzed to better acquaint the technician with circuit operation. The actual circuit diagram, including the various switching functions, is included in the instruction book provided by the equipment manufacturer.

ADVANTAGES OF SINGLE-SIDEBAND COMMUNICATIONS

A comparison of the frequency and power relationships between single-sideband transmission and conventional a-m transmission is illustrated in figure 14-1. The SSB system is illustrated in part A of this figure. Only one sideband, peak-envelope power (PEP) of 50 watts, is needed to transmit intelligence. None of the power is contained in the carrier or in the upper sideband. Although the lower sideband is transmitted the upper sideband could have been transmitted just as easily. In

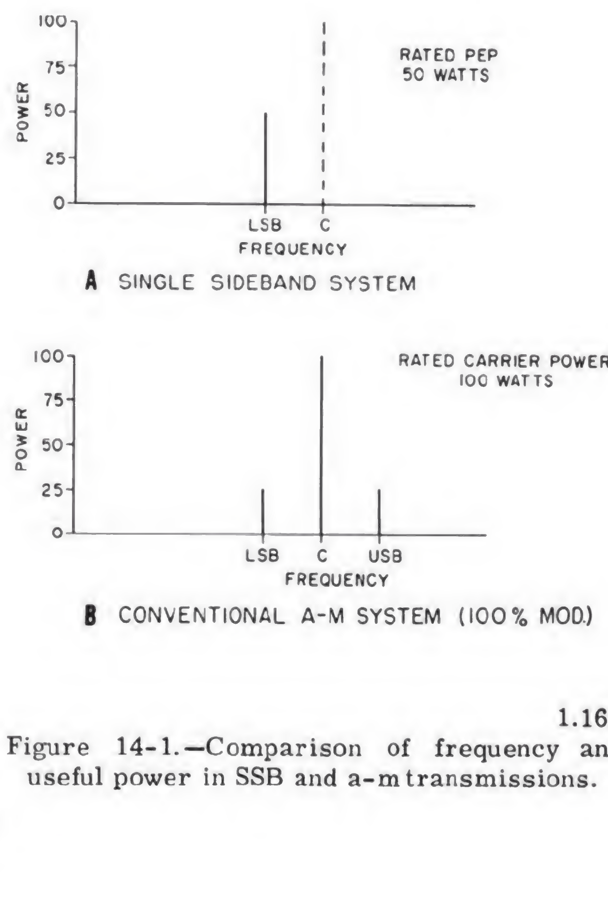

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Figure 14-1.—Comparison of frequency and useful power in SSB and a-m transmissions.

some systems both sidebands may be utilized independently.

In the familiar a-m system of communication (fig. 14-1B), the radiated signal includes the carrier and an upper and a lower sideband frequency for each frequency in the modulating signal. For example, if a 1-mc carrier is modulated by a 1-kc tone, the radiated signal will include the 1-mc carrier, the lower sideband frequency (1 mc -1kc = 999 kc), and the upper sideband frequency (1 mc + 1 kc = 1001 kc). If the modulating signal contains many frequencies, there will be, of course, many frequencies in the sidebands. In this system of transmission, none of the transmitted intelligence is contained in the carrier; therefore all of the power put into the carrier is wasted insofar as transmitting intelligence is concerned. Likewise, because duplicate information is contained in each of the two sidebands, the intelligence content of the transmitted signal could be recovered from one sideband only.

In a conventional a-m system where both sidebands and the carrier are transmitted, the power in the sidebands is dependent upon the amount of modulation. For 100% modulation the power in the sidebands is equal to one-half that in the carrier. Thus, a conventional a-m transmitter with 100-watts carrier power will have 50 watts in the sidebands (25 watts in the upper sideband and 25 watts in the lower sideband) at 100% modulation, making the total power transmitted 150 watts (fig. 14-1B). It can be seen, then, that two-thirds of the total radiated power in a conventional a-m system (assuming 100% modulation) is in the carrier and is therefore not useful in conveying intelligence.

When the r-f signal is demodulated in the conventional a-m system, the audio output is a combination of the upper and lower sidebands. In this conventional type of detection (known as coherent detection) the audio output is proportional to the power contained in the two sidebands.

In a single-sideband system, only one sideband is transmitted and therefore the audio output of the SSB receiver is proportional to the power contained in the one sideband.

It therefore becomes apparent that an SSB transmitter and an a-m transmitter will perform equally (same signal-to-noise ratio) under ideal propagating conditions, if the total sideband power of the two transmitters is equal. Considering the relationship between sideband power and carrier power in a conventional a-m system, it is evident that an SSB transmitter will perform as well as an a-m transmitter of twice the power rating under ideal propagating conditions. Thus, a single-sideband transmitter rated at 50 watts will produce the same signal intelligence level at a receiver as a conventional a-m transmitter rated at 100 watts of carrier power (see figure 14-1).

As propagating conditions become less than ideal, the SSB system will show even a greater advantage over an a-m system. An a-m transmission is subject to deterioration under poor propagation conditions because all three components of the transmitted signal (the upper sideband, the lower sideband, and the carrier) must be received exactly as transmitted to realize perfect reception. Because there is only one component in the transmitted signal for an SSB system, it is not so affected by poor propagating conditions. Studies have shown that the SSB system will give from zero to nine decibel improvement under various conditions of propagation when the total sideband power in SSB is equal to that in amplitude modulation (fig. 14-2).

Note that under average conditions, the SSB system shows about a 3 db advantage over the a-m system. In other words, in normal use, an SSB transmitter rated at 100 watts (PEP) will give equal performance with an a-m transmitter rated at 400-watts carrier power.

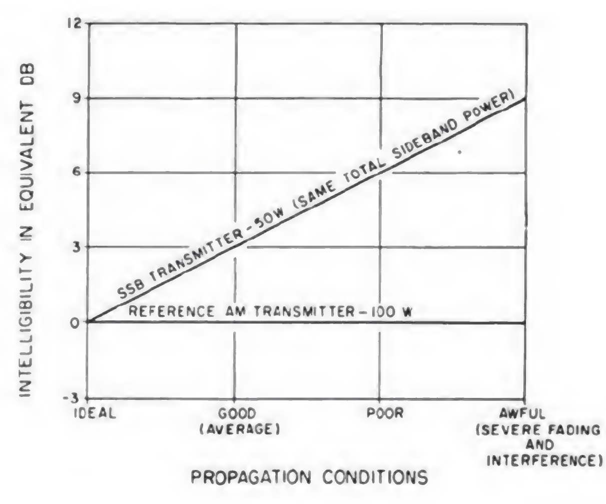

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Figure 14-2.—Comparison of amplitude modulation and SSB under varying propagation conditions.

As far as bandwidth is concerned (assuming one sideband only), the SSB system requires only about one-half the frequency spectrum that the conventional a-m system requires.

The advantages of SSB over the conventional a-m system may be summarized as follows:

1. The SSB transmitter will perform as well as an a-m transmitter of twice the power rating under ideal propagating conditions. Under average conditions there is also an additional 3 db advantage of a SSB system over an a-m system having the same sideband power.
2. If only one sideband is used, the SSB system requires only one-half as much r-f spectrum as the a-m system.
3. The SSB transmitting system uses smaller units than comparable a-m units because less power is required.
4. By virtue of less power in the antenna, lower voltages are required, with attendant reduction of potential breakdown.
5. The SSB system is subject to less noise interference because the bandpass is narrower.

PROBLEMS INVOLVED IN SINGLE-SIDEBAND COMMUNICATIONS

The advantages of SSB cannot be realized without the use of specially designed components and circuitry. First of all, there is the problem of frequency stability, especially when the carrier is totally suppressed. This means that the oscillators in the transmitter and in the receiver must not drift more than a few cycles. Actually, the permissible frequency variation for SSB systems is 1/100th of that for an a-m system.

In one type of double-sideband generation, filters of extreme selectivity are needed. Linear power amplifiers, which are difficult to design, are also needed.

Another problem, when SSB equipment is used on high-speed aircraft, is that of Doppler shift. This is especially noticeable at the higher radiated frequencies.

FUNCTIONAL BLOCK DIAGRAM OF A TYPICAL SSB SYSTEM

A block diagram of an SSB transceiver is shown in figure 14-3. This is a single-sideband, suppressed-carrier, transmitter-receiver combination. Some examples of SSB systems are the AN/URT-32, the AN/WRT-2, and the AN/WRR-2. The operating frequency of this system is selected from one of four pretuned channels, and the signal is transmitted on the lower sideband only.

The SSB system illustrated in figure 14-3 consists of a transmitter-receiver chassis and a power supply chassis.

As may be seen in the diagram, three crystal oscillators are used on transmission and reception. The three oscillators, and the balanced modulators that they feed, are needed to heterodyne the frequency up to the desired radiation frequency and down to the desired demodulation frequency.

Transmitter Section

On transmission, the modulating signal (1 kc is assumed) from the tone oscillator (block 1) or the microphone is amplified in the microphone amplifier (block 3).

From block 3 the signal is fed to block 4, a balanced modulator. Here the 1-kc signal is combined with the 250-kc signal from the crystal oscillator (block 5) to produce lower and upper sideband frequencies (250 kc - 1 kc = 249 kc, and 250 kc + 1 kc = 251 kc). The 250-kc oscillator frequency is suppressed in the balanced modulator. The balanced modulator is described in more detail later in this chapter.

From block 4 the two sideband frequencies are fed to a mechanical filter (block 6). The mechanical filter is a mechanically resonant device that receives electrical energy, converts it into mechanical vibration, then converts the mechanical energy back into electrical energy (using the magnetostriction principle) at the output. This filter resonates with, and passes, the upper sideband (251 kc), but suppresses the lower sideband (249 kc).

From block 6 the 251-kc signal is fed to the second balanced modulator (block 7). Here the 251-kc signal is combined with the 1150-kc signal from block 8. Two sidebands (899 kc and 1401 kc) are produced, and the crystal frequency (1150 kc) is suppressed. Included in this block is a tuned r-f transformer, which passes the upper sideband (1401 kc) and suppresses the lower sideband (899 kc).

The 1401-kc upper sideband frequency from block 7 is fed to the third balanced modulator (block 9) where it is combined with the 15,650-kc signal (assume channel 4 operation) from block 10. The 15,650-kc frequency is suppressed, and the two sidebands (14,249 kc and 17,051 kc) are fed to the tuned r-f circuits in

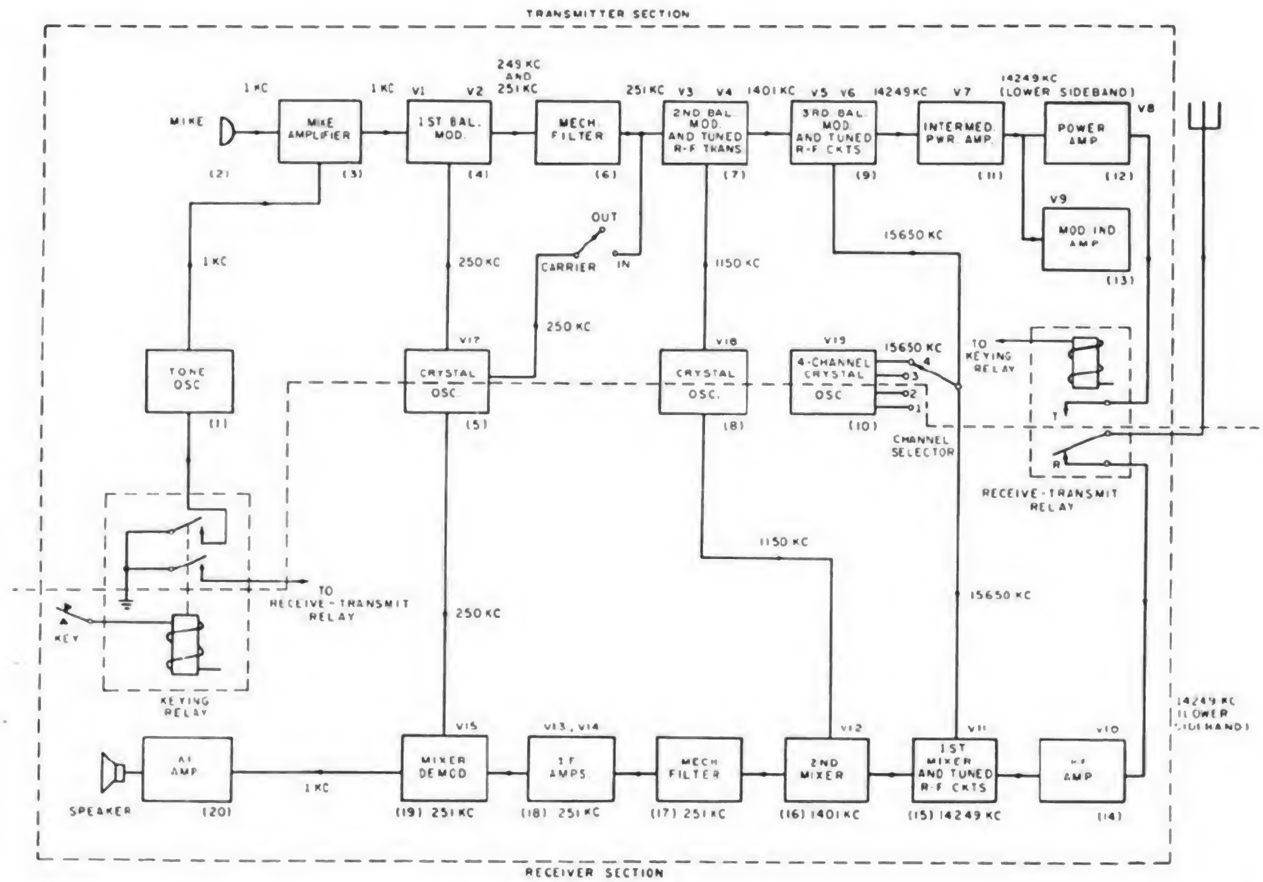

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Figure 14-3.—Block diagram of an SSB transceiver.

block 9. Only the lower sideband (14,249 kc) is fed to the intermediate power amplifier (block 11) and the power amplifier (block 12).

The lower sideband frequency of 14,249 kc is applied to the antenna when the receive-transmit switch is in the TRANSMIT position. The receive-transmit relay contacts make electrical continuity between the antenna and receiver at all times except when actually transmitting.

The modulation indicator amplifier (block 13) amplifies the signal from the power amplifier grids and applies it to the peak modulation indicator (a lamp), which indicates modulation peaks.

Receiver Section

Reception is essentially the reverse of transmission. For simplicity, it is assumed that the incoming signal is 14,249 kc and that the intelligence signal is a 1-kc tone; the nominal carrier is therefore 14,250 kc. Note that with this SSB system the carrier is not transmitted. The 14,249-kc signal is fed (when the receive-transmit switch is in the RECEIVE position) to the r-f amplifier (block 14).

From the r-f amplifier the 14,249-kc signal is fed to the first mixer (block 15) where it is mixed with the 15,650-kc signal from block 10. The output contains the sum and difference frequencies, 29,899 kc and 1401 kc, respectively. The difference frequency (1401 kc) passes through the tuned r-f circuits to the second mixer (block 16).

In the second mixer the 1401-kc signal is mixed with the 1150-kc frequency from block 8 to produce sum and difference frequencies, 2551 kc and 251 kc, respectively. The mechanical filter (block 17) is tuned to 251 kc, and

this is the only frequency that is passed through the i-f amplifier to the mixer demodulator (block 19).

In the mixer-demodulator the 251-kc, i-f, signal is mixed with the 250-kc frequency from block 5 to produce sum and difference frequencies, 501 kc and 1 kc, respectively. The 501-kc frequency is eliminated, and the 1-kc signal is then amplified in block 20 and applied to the speaker.

Transmission With Carrier

To make this equipment compatible with a-m equipment now in use, provision is made for inserting a carrier signal after the mechanical filter. (At the input of the second balanced modulator, see the transmitter section of figure 14-3.)

The 250- and 251-kc signals are heterodyned in the second and third balanced modulators. The frequency difference between carrier and sideband is maintained in the output the same as in the input to the second balanced modulator. Assume channel 4 operation (15,650 kc). The carrier will then be 14,250 kc, and the lower sideband (produced by the 1-kc tone) will be 14,249 kc. The combined signal can be detected by conventional a-m receivers that are capable of being tuned to this frequency.

SIMPLIFIED CIRCUIT DIAGRAM

Figure 14-4 is a simplified schematic diagram of the circuits included in the transmitter-receiver chassis. The audio input section (including the microphone amplifier and the tone oscillator) is treated later; the audio output section is also treated later. Power supplies are treated in Basic Electronics, NavPers 10087; and, because the power supply is conventional, it is not covered in detail in this chapter.

CRYSTAL OSCILLATORS

The functions of the various circuits in the SSB system have been discussed in terms of the functional block diagram. It is convenient to begin the brief analysis of the circuits in the transmitter-receiver chassis (fig. 14-4) with the crystal oscillators.

Two of the crystal oscillators, V17 and V18, are of fixed frequency (250 kc and 1150 kc), and the necessary crystals are supplied with the equipment. The four-channel-frequency crystals used with V19 are supplied separately. The nominal carrier frequency (the carrier is not transmitted) determines the frequency of the channel-frequency crystals. When channel-frequency crystals are to be selected it is a simple matter to determine the correct crystal frequencies: simply add 1400 kc to the desired nominal carrier frequency for each channel. For example, assume that the channel selector switch is set to channel 4 and that a nominal carrier frequency of 14,250 kc is to be used. The crystal frequency must then be 14,250 kc plus 1400 kc, or 15,650 kc.

The 250-kc crystal oscillator, V17, feeds the first balanced modulator, V1-V2, on transmission and the de-modulator, V15, on reception. The 250-kc crystal, as well as the others, is enclosed in an oven where a constant temperature is maintained. As indicated in figure 14-4, the plate of V17 is supplied from the 150 v regulated supply. The crystal is connected (through a coupling capacitor) between grid 3 and grid 1, making, in effect, an electron-coupled oscillator.

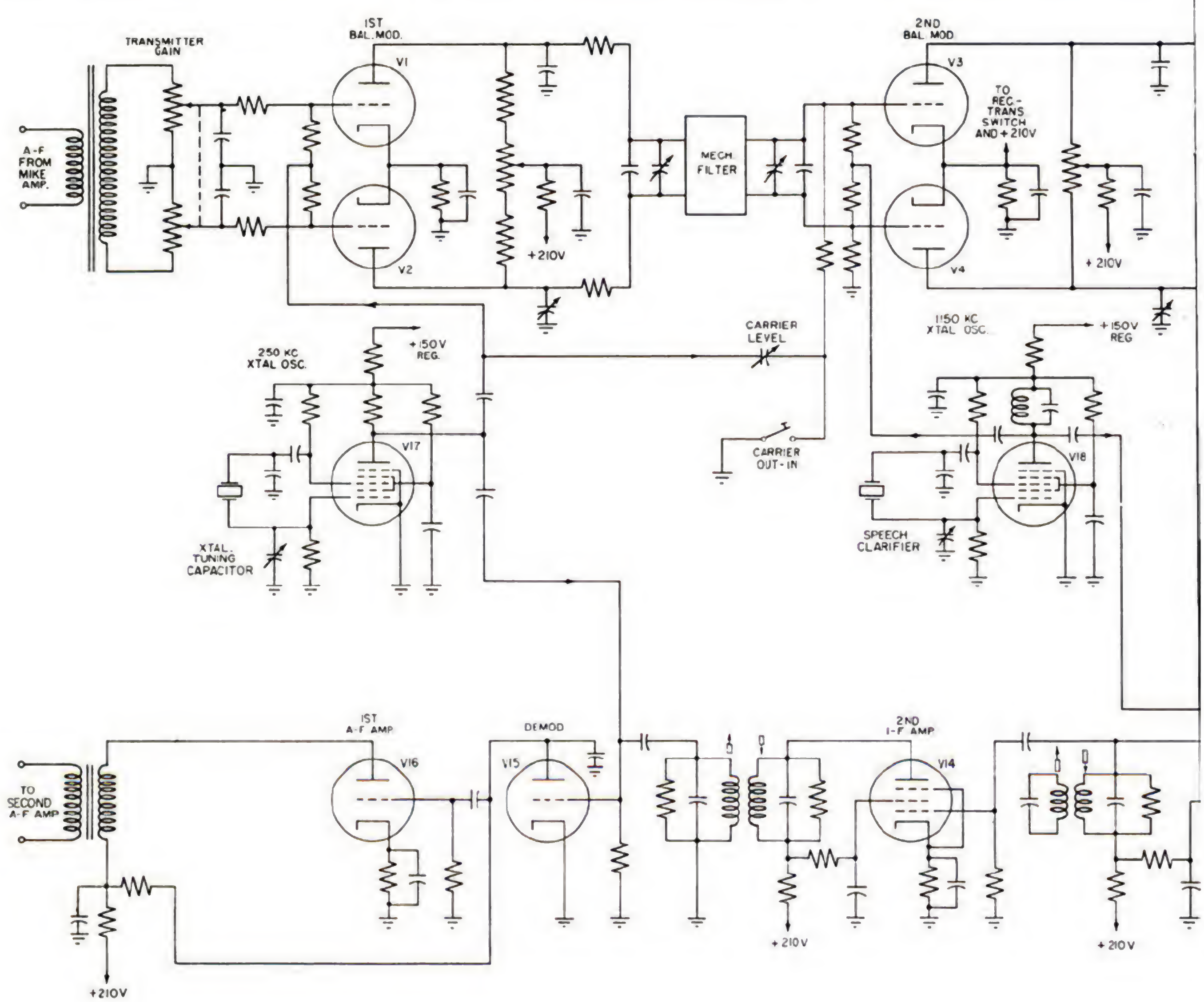
The crystal tuning capacitor is used to vary the oscillator frequency over a small range.

Various types of oscillators are treated in Basic Electronics, NavPers 10087. The crystal may be connected between various tube elements—for example between the first and third grids of a pentagrid tube, between the screen grid and control grid of a pentode, or between the plate and grid or grid and cathode of a triode.

The 1150-kc oscillator, V18, operates in a manner similar to the 250-kc oscillator. However, the tuning capacitor in this instance has a front-panel control, called the speech clarifier. By adjusting this capacitor the operator may bring the oscillator frequency exactly to that of the station he is working. This oscillator feeds the second balanced modulator, V3 and V4, on transmission and the second mixer, V12, on reception.

The channel-frequency oscillator, V19 (a simplified diagram of which is shown in figure 14-5) employs a power pentode and any one of the four crystals. The position of the switch determines which of the crystals will be used. This oscillator feeds the third balanced modulator, V5 and V6, on transmission and the first mixer, V11, on reception.

As may be seen in the figure, the crystal is connected between the screen grid and the control



grid. Feedback occurs through the 0.01-μf capacitor (coupled to the screen grid) and the parallel combination of the 1.24-μh choke and the 1200-ohm resistor. Grid voltage is developed across a 47,000-ohm resistor for channels 1 and 2 and across a 22,000-ohm resistor for channels 3 and 4. For each position of the channel selector switch a 2.3- to 15-$\mu\mu$f trimmer capacitor between grid and ground is available for adjusting the oscillator circuit to the desired frequency.

The crystal-oscillator, output-level equalizer employed in the output of the channel-frequency oscillator limits the output (fed to the third balanced modulator, V5 and V6, and the first mixer, V11) to approximately 1.8 v, which is the voltage drop across the 180-ohm resistor. The limiting action may be explained by the use of the simplified diagram shown in figure 14-6. In this diagram the 180-ohm resistor has been replaced by a 2 v battery (2 v are used

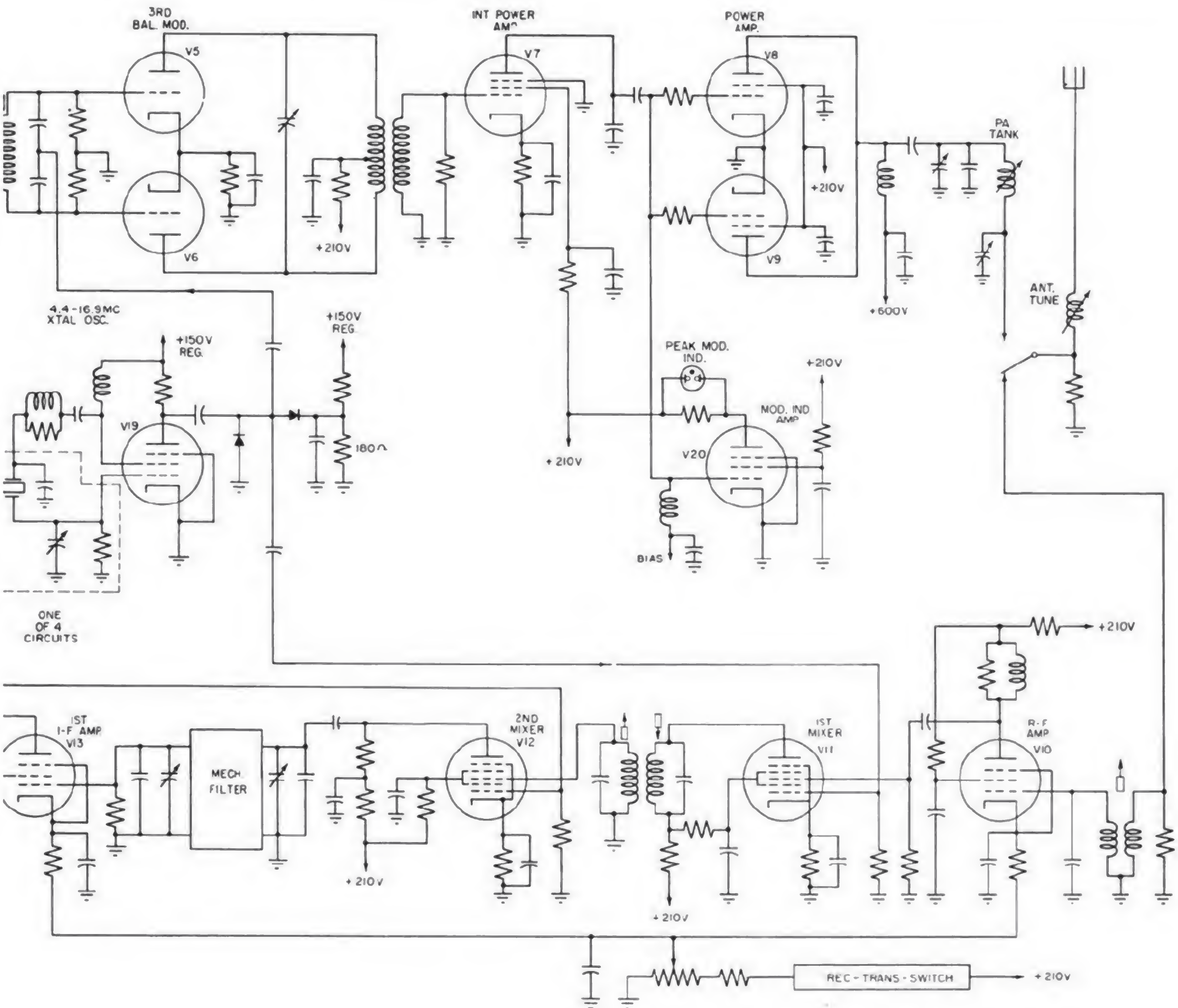


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Figure 14-4.—Simplified circuit diagram of the transceiver chassis.

to avoid the decimal), and only the plate and cathode connections of the oscillator tube, V19, are shown. The easy direction of electron flow in the diodes is opposite to that of the arrow in the diode symbol.

The input voltage, E_{a-g}, swings 50 v above and 50 v below an assumed value of 100 v. The voltage E_{a-b}, across capacitor C swings 49 v above and 49 v below 99 v because of the action of the 2 v battery. The voltage, E_{b-g}, fed to the coupling capacitor is a series of pulses that swings between 0 and 2 v. Because of the action of the coupling capacitor and because the diodes are not perfect one-way conductors, the voltage fed to the load is essentially of a sine waveform having a peak-to-peak value of two volts.

At 0°, it is assumed that E_{a-g} is at its peak value of 150 v; E_{a-b} is at its peak value of 148 v, and E_{b-g} is at its maximum value of 2 v.

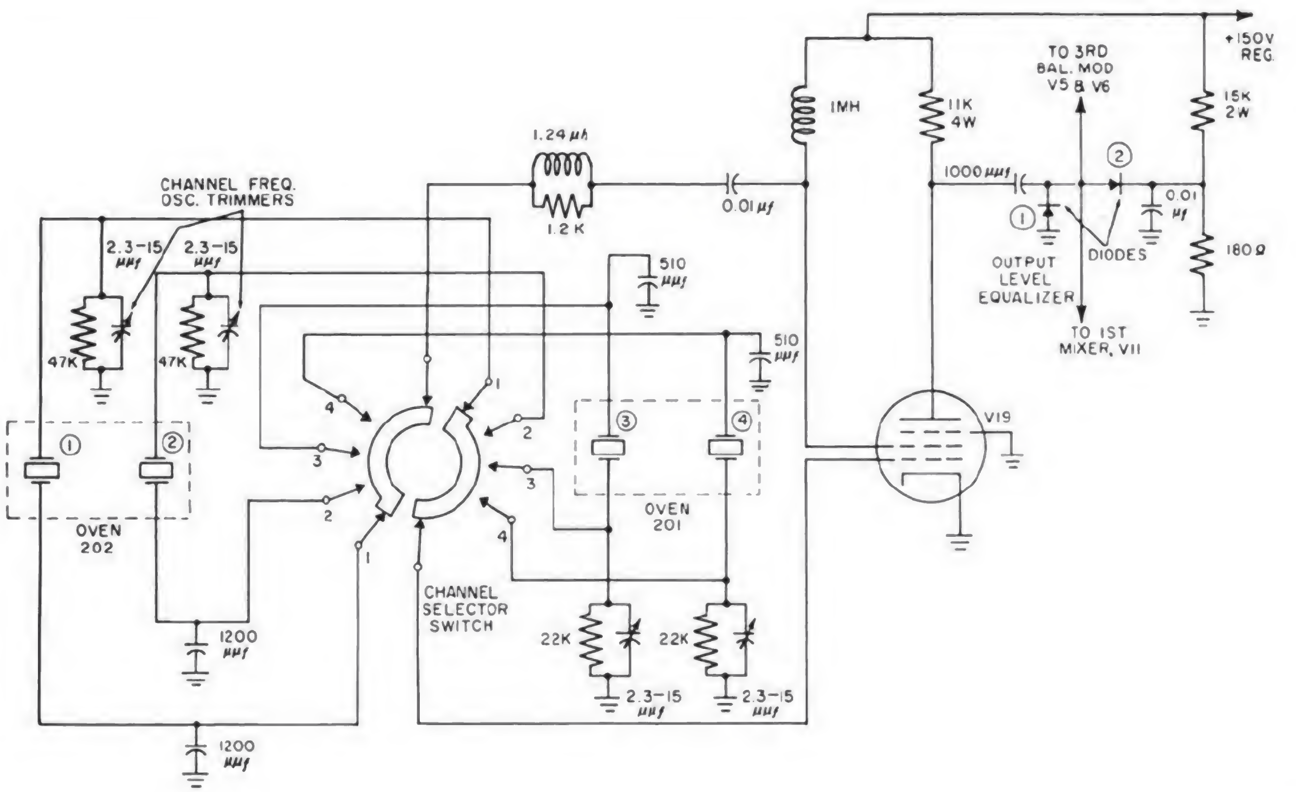

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Figure 14-5.—Simplified diagram of the channel-frequency oscillator.

These values have been established during the previous half cycle.

When E_{a-g} decreases to 149 v, E_{a-b} remains at 148 v, and E_{b-g} decreases to 1 v. When E_{a-g} decreases to 148 v, E_{a-b} still remains at 148 v, and E_{b-g} decreases to 0 v. When E_{a-g} decreases to 147 v, C begins to discharge through diode 2, and the discharge continues to the 180° point, thus maintaining point B at ground potential during this portion of the input cycle.

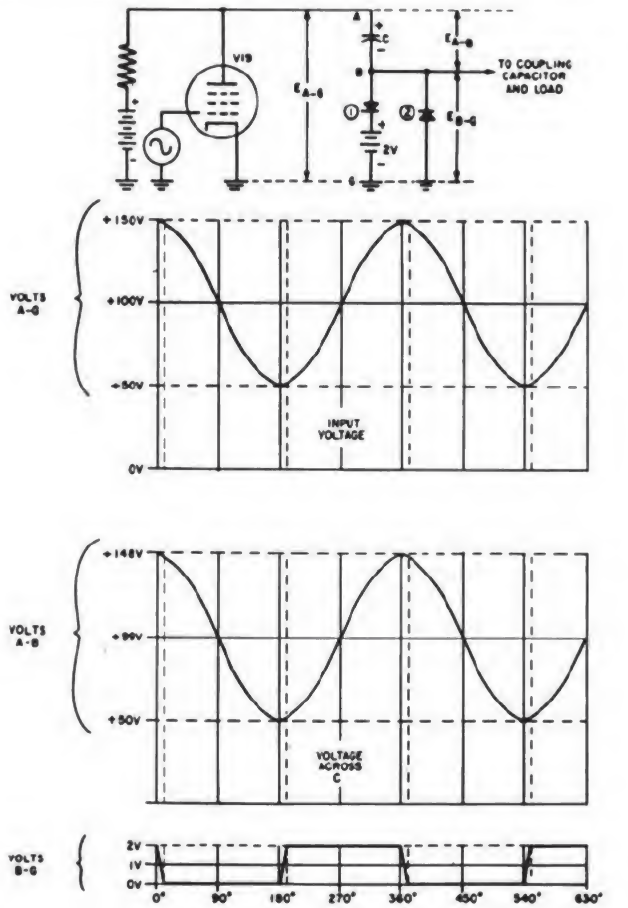
At 180°, E_{a-g} is 50 v and E_{a-b} is also 50 v. When E_{a-g} increases to 51 v, E_{a-b} remains at 50 v, and E_{b-g} increases to 1 v. When E_{a-g} increases to 52 v, E_{a-b} still remains at 50 v, and E_{b-g} increases to 2 v. When E_{a-g} increases above 52 v, diode 1 conducts, thus maintaining E_{b-g} at 2 v until the 360° point is reached. Immediately following 180° the rising voltage, E_{a-g}, is imparted to the load because neither diode is conducting. The rise in voltage across the load is terminated at the instant diode 1 conducts and is limited to 2 v during this half cycle. Similarly, following 360° the falling E_{a-g} voltage change is imparted to the load because neither diode is conducting. At the instant E_{b-g} becomes zero, diode 2 conducts, and the output remains at zero potential during this half cycle.

METHODS OF GENERATING SSB SIGNALS

There are two common methods of generating single-sideband signals. One method involves the use of the balanced modulator and a suitable filter. It is commonly called the FILTER METHOD. The other involves the use of phasing circuits, and is commonly called the PHASING METHOD. Both methods are discussed in the following sections.

FILTER METHOD

A simplified circuit diagram of the first balanced modulator (V1 and V2 in block 4,



1.165
Figure 14-6.—Oscillator output level equalizer.

figure 14-3) is given in figure 14-7. The 250-kc signal generated by the crystal oscillator is applied in the same phase to the grids of V1 and V2, and is therefore suppressed in the output. The reason the carrier is suppressed may be explained as follows: (1) at a given instant the crystal oscillator drives both grids an equal amount in a positive direction, (2) plate current then rises an equal amount in both tubes, (3) current flows from both plates toward the movable contact on the balance control, (4) the voltages across both plate loads are equal and opposite, and (5) no difference in potential at the carrier frequency exists across the input to the mechanical filter, and hence the carrier is suppressed.

The amount of carrier suppression depends on the degree of balance that is maintained. Under conditions of perfect balance, the carrier is completely suppressed.

The 1-kc signal fed through the a-f transformer arrives at the grids of tubes V1 and V2, 180° out of phase; and, as in any push-pull circuit (see Basic Electronics, NavPers 10087-A), a signal appears at the output. However, the audio component is not passed by the filter or any of the other r-f circuits.

The two sideband components (sum and difference frequencies of 249 kc and 251 kc) generated in the circuits of V1 and V2 are not balanced out in the plate circuits and therefore appear in the output. They are not balanced out for the same reason that the audio component is not balanced out. That is, each of these frequencies applied to the grid of V1 is 180° out of phase with the corresponding frequency applied to the grid of V2.

Because only the upper sideband is to be passed to the second balanced modulator (block 7, figure 14-3), the mechanical filter is designed to pass 251 kc and to eliminate 249 kc.

PHASE-SHIFT METHOD

The phase-shift method of generating SSB differs considerably from the previously described filter method. In the phase-shift method, two balanced modulators are connected in an equivalent push-pull circuit (fig. 14-8). The input signals are shifted 90° with the result that either the sum or the difference frequencies are canceled in the output, thereby eliminating the need for narrow band filters and additional stages in cascade. In figure 14-8A, the upper sideband is suppressed and the lower sideband is radiated; and in figure 14-8B, the lower sideband is suppressed and the upper sideband is radiated. Actually, the arrangement in part A can be changed to that in part B by means of a switching circuit, and this is the usual method of operation. Thus, the operator has a choice of operating on either the lower or the upper sideband.

Assume that in figure 14-8A, the modulating frequency is 1 kc and that the r-f carrier oscillator is 5 mc. The a-f signal is fed directly to balanced modulator 1; it is also fed to the a-f phase shifter. From the a-f phase shifter the signal is shifted 90° and fed to balanced modulator 2.

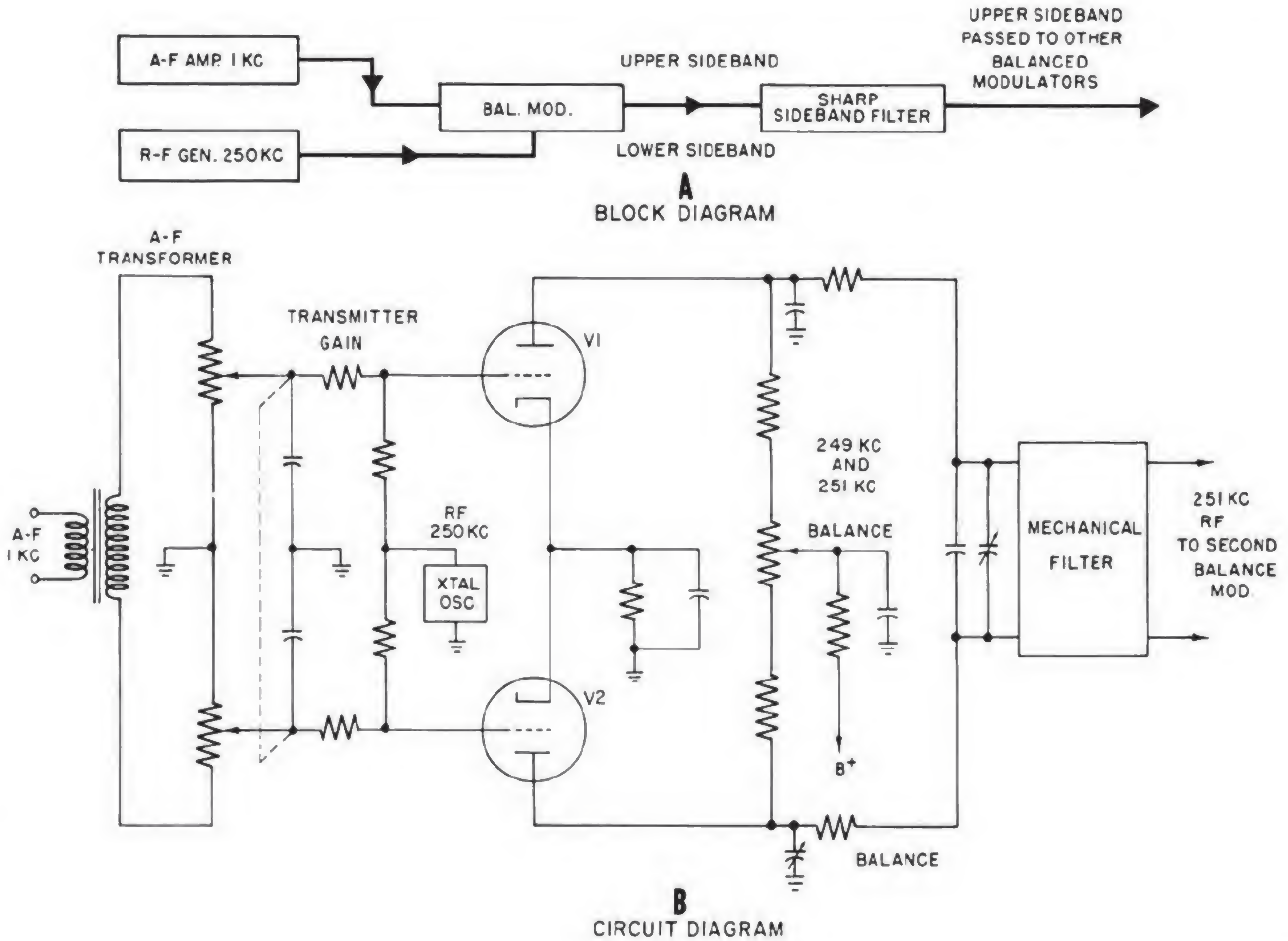


Figure 14-7.—Block and circuit diagram of a balanced modulator.

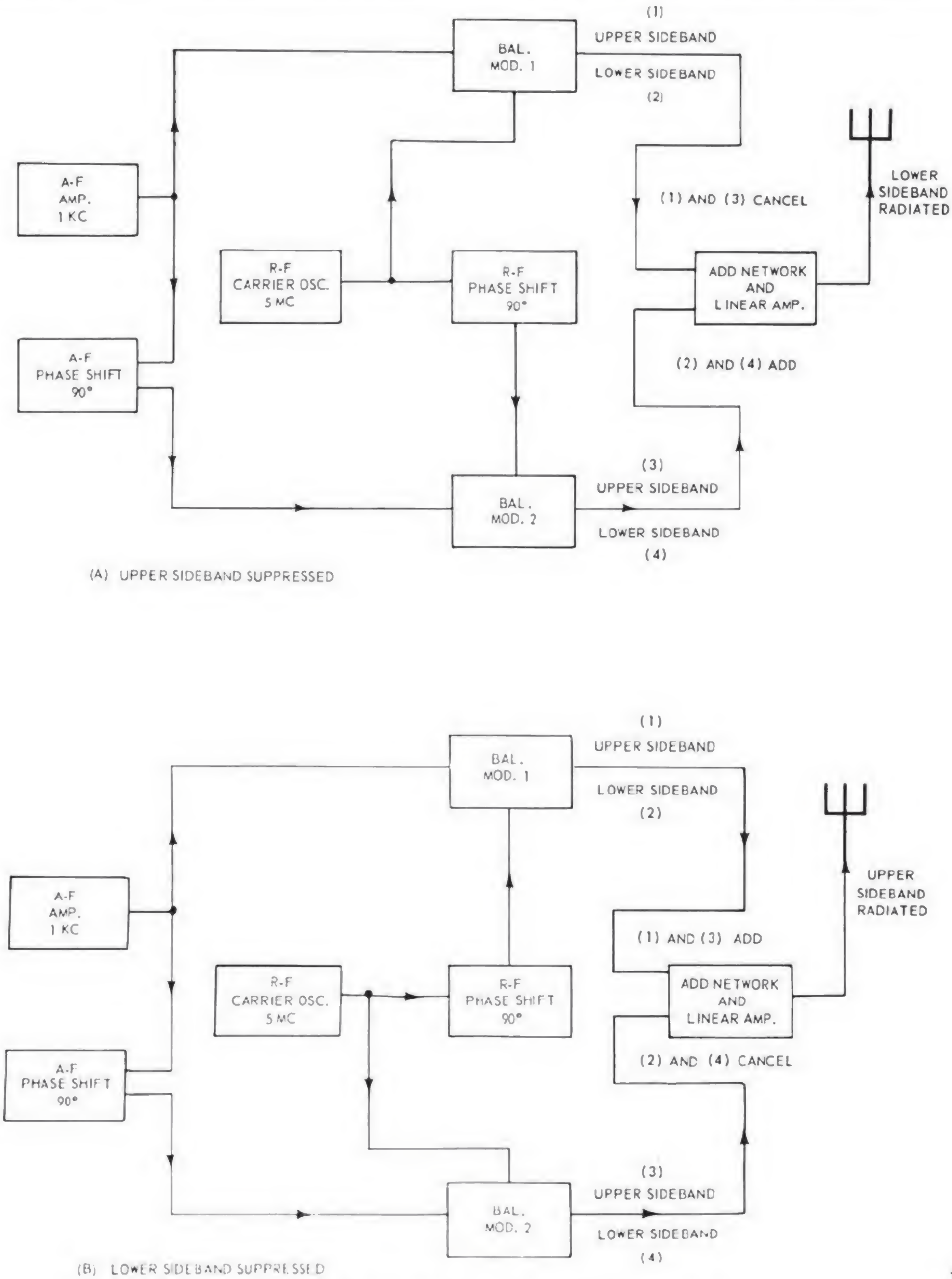
The r-f carrier is fed to balanced modulator 1 with no shift in phase; it is also fed to balanced modulator 2 through the r-f phase shifter.

In balanced modulator 1 and a-f and r-f signals are combined to produce upper and lower sideband frequencies. The upper sideband from balanced modulator 1 is 180° out of phase with the upper sideband from balanced modulator 2, and therefore these two signal components are canceled in the add network. However, the lower sideband from balanced modulator 1 is in phase with the lower sideband from balanced modulator 2, and these components add in the add network.

As in any balanced modulator, the carrier (5 mc, in this case) is balanced out and does not appear in the output.

In figure 14-8B, the a-f phase-shifted signal is fed to balanced modulator 2, and the r-f phase-shifted signal is fed to balanced modulator 1. As indicated in the figure, the upper sideband from balanced modulator 1 combines in phase with the upper sideband from balanced modulator 2. However, the two lower sidebands combine 180° out of phase (one is advanced by 90° and one is retarded by 90°); and these components are cancelled in the add network. As in part A, the carrier is balanced out and does not appear in the output.

It is obvious that, if the unwanted sideband is phased out by means of the phase-shift circuits and the balanced modulators, a narrow-band filter is unnecessary.



1.167

Figure 14-8.—Phase-shift method of SSB generation.

COMPARISON OF FILTER AND PHASE-SHIFT METHODS OF SSB GENERATION

The audio input and the linear power amplifier circuits used in each of the two methods of SSB generation are comparable. However, there are great differences in some of the other circuits.

Modulation in the filter system must take place at a low radio frequency (250 kc, for example) because the percentage of separation of sidebands at low carrier frequencies is much greater than at high carrier frequencies. The filters (electromechanical or crystal lattice) must be very selective and pass only the desired narrow band of frequencies. This will be either the lower or the upper sideband.

Because the system starts with a low generated frequency, (perhaps 250 kc) is must be heterodyned in a sufficient number of balanced modulator stages to bring it to the desired radio frequency.

In the filter system it is difficult and expensive to switch from one sideband to the other. However, this system is very stable; and once the initial adjustments are properly made, the equipment should operate with a minimum of internal adjustments.

Generation of SSB in the phase-shift system may take place in one equivalent push-pull stage at the radiated frequency, and thus the heterodyning process may be minimized. Because the unwanted sideband is phased out in the balanced modulator, the use of expensive electromechanical or crystal lattice filters is avoided.

In the phase-shift method, either of the sidebands may be used. This is accomplished by means of a simple switching arrangement. A major disadvantage of the phase-shift method is that the phase-shift networks require critical adjustments and are likely to require attention from time to time.

NARROW BAND FILTERS

The narrow band filters used after the first balanced modulator in transmitters employing the filter method of SSB generation and after the mixers in their associated receivers must have very high Q's and sharp cutoff characteristics. Mechanical or crystal lattice filters may be used. Crystal lattice filters have Q's of 10,000 to 200,000 or even higher. Mechanical filters have Q's of 2000 to 10,000 or more. Compact lattice filter units have been designed to operate up to 40 mc. However, at lower frequencies (for example, 200 to 250 kc) mechanical filters have proven to be compact and durable. Both types are discussed in the following paragraphs.

Mechanical Filters

Several types of mechanical (electromechanical) filters have been designed for use with SSB equipment. Fundamentally, they all operate on the same principle. Metal rods or disks are mounted in a container in such a way as to form a group of mechanical resonating elements. Energy is put into the system by means of a magnetostrictive transducer, and energy is taken out the same way. Only a relatively narrow band of frequencies can cause the resonating elements to respond. Therefore, only these frequencies can produce a signal in the output transducer.

One type of disk mechanical filter (actually an electromechanical filter) is illustrated in a simplified form in figure 14-9. The signal is fed into the input coil, which causes the first disk to vibrate because of magnetostrictive action of the coil and the driving wire. The wire is a magnetic material. The vibrations are coupled to the remaining disks by means of the coupling wires. The vibrations of the last disk cause the output driving wire to vibrate, and by the inverse magnetostrictive effect an output signal is developed in the output coil.

The disk resonators are precisely ground to resonate at frequencies very close to the center frequency of the pass band. The width of the pass band depends on the coupling elements, the center frequency depends on the size of the resonator elements, and the selectivity depends on the number of resonant elements.

A simplified diagram of another type of mechanical filter is illustrated in figure 14-10. This filter has seven resonant sections, and two quarter-wave end sections for support. The center resonator is encircled by a "snubber" bracket, (not shown) which prevents excessive excursions under shock. The hermetically sealed housing into which the filter is mounted contains a dry inert gas. This filter vibrates with a twisting motion (torsional vibration); the twisting motion is passed from one element to another through the coupling sections.

As in the case of the disk-type filter the center frequency depends on the resonant

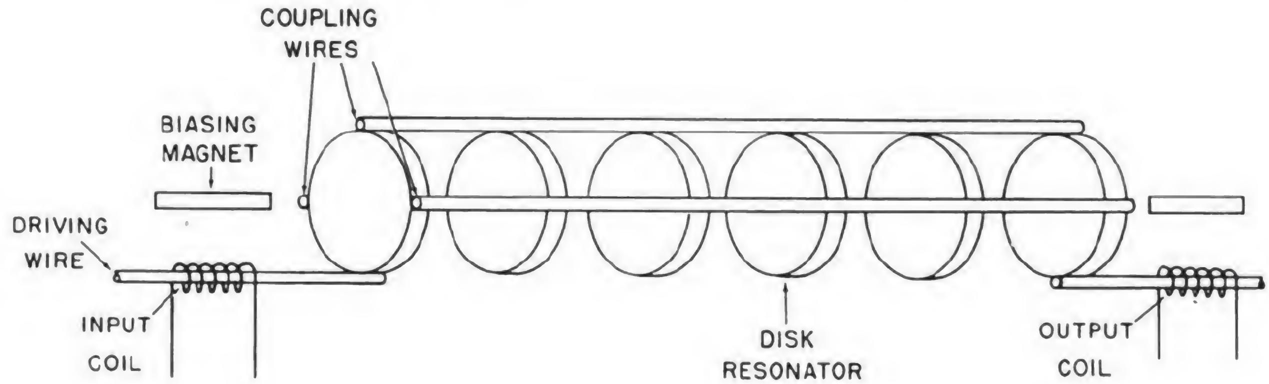


Figure 14-9.—Disk-type mechanical filter.

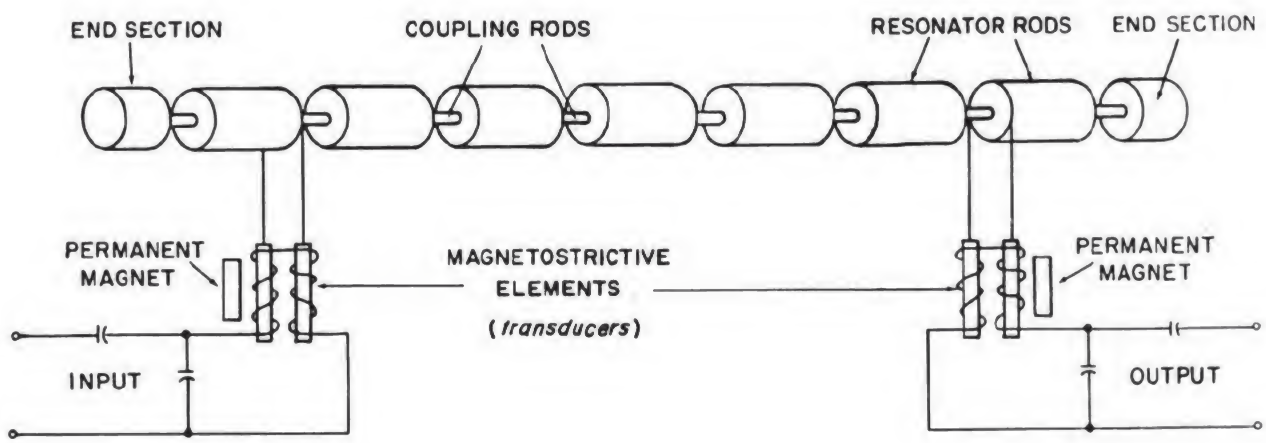


Figure 14-10.—Mechanical filter used with an SSB system.

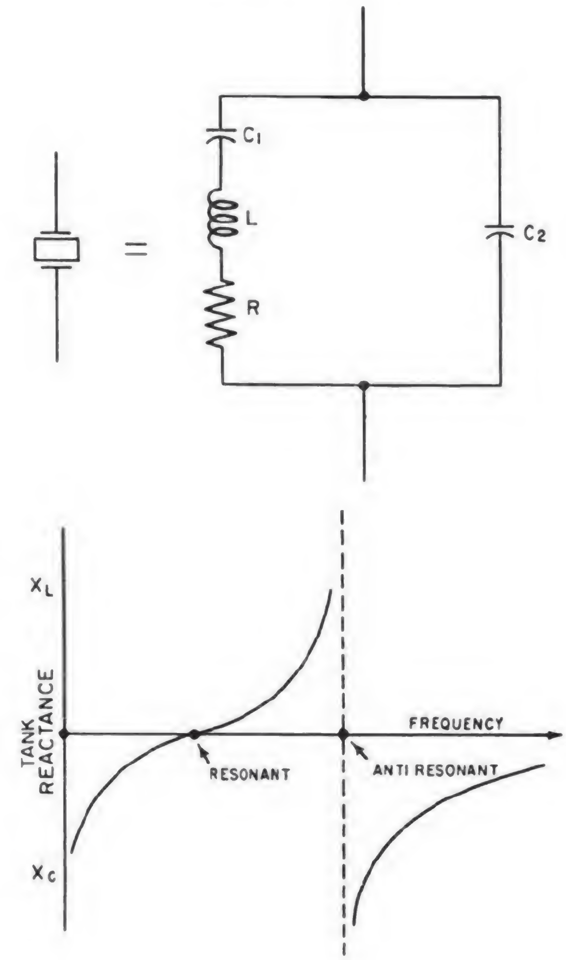
frequency of the tuned elements, the selectivity depends upon the number of tuning elements, and the width of the pass band depends on the design of the coupling elements.

The transducers at the input and output are specially processed ferrite rods. The resonator rods are made of a specially prepared nickel alloy heat-treated to maintain an essentially constant frequency even during wide temperature changes.

Crystal Lattice Filters

The equivalent electrical circuit of a quartz crystal is illustrated in figure 14-11. Capacitor C1 represents the reciprocal of the crystal stiffness—that is, compliance, which is the equivalent of capacitance in the electrical system; L represents the electrical equivalent of the crystal mass that is effective in causing mechanical vibration; and R is the electrical equivalent of internal resistance. Capacitance C2 represents the capacitance of the crystal holder plates with the crystal plate between them. Because of the very large value of the crystal Q, the equivalent circuit may be considered to be entirely reactive for most filter applications.

As indicated on the reactance curve (fig. 14-11) series resonance occurs at the point where the reactance curve crosses the zero line. In general, the resonant (series resonant)



1.170

Figure 14-11.—Equivalent electrical circuit of a crystal in its holder.

and antiresonant (parallel resonant) points will be fairly close together. However, by the proper use of input and output reactances the points may be spread apart for filter applications.

Typical crystal lattice circuit arrangements are illustrated in figure 14-12A. Additional elements may be added in the branches that are indicated by dotted lines.

A circuit that may be used in a SSB system is illustrated in figure 14-12B. The parallel-connected crystals are frequency matched as close as possible; the series-connected crystals are also matched. The resonant frequency of the parallel crystals is perhaps 3 kc higher than that of the series crystals. Both the input and the output circuits are tuned to the center frequency of the pass band. In addition to the capacity of the trimmer capacitor (used for adjustment purposes) there is, of course, the distributed capacity of the crystal elements.

The crystal lattice filter is, in effect, a bridge circuit, as illustrated in simplified form in figure 14-13. Assume that the center frequency at the input is 101.5 kc and that the crystals have resonant frequencies, as shown.

At 101.5 kc, the reactances of crystals 1 and 4 will be capacitive (see reactance curve, fig. 14-11), and the reactances of crystals 2 and 3 will be inductive. The bridge will therefore be unbalanced, and a voltage will appear at the output. The same type of reasoning may be applied for other frequencies within the bandpass. For simplicity, the effects of the input and output inductances and the distributed capacitances have been neglected.

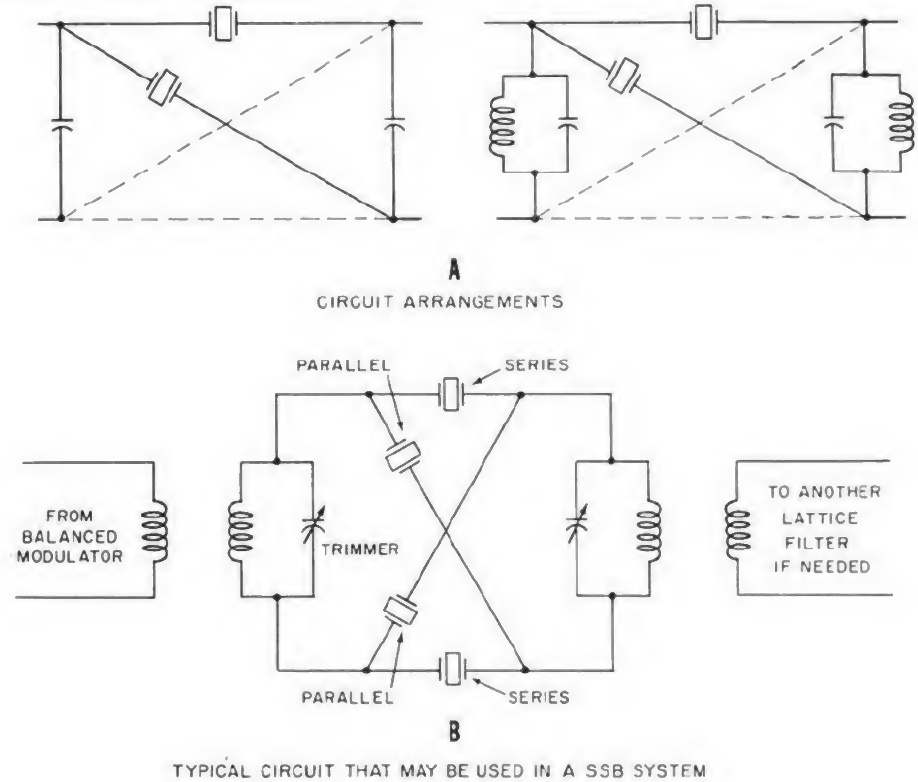


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Figure 14-12.—Crystal lattice filter configurations.

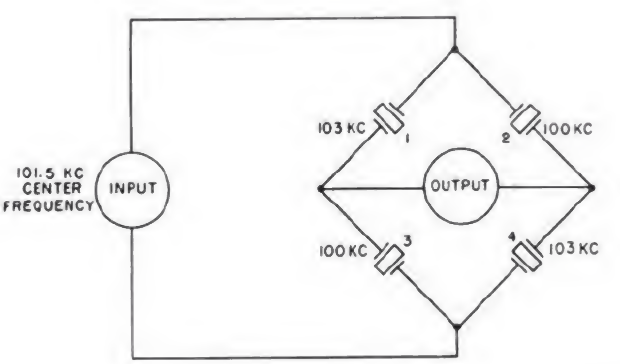

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Figure 14-13.—Simplified equivalent bridge circuit.

AUDIO CIRCUITS

With the exception of the receiver first audio amplifier, the audio input and output circuits are included in the power supply chassis. For simplicity, they were not included in the simplified schematic diagram of figure 14-4. Both the audio input and output sections are treated briefly in the following paragraphs.

INPUT SECTION

A simplified schematic diagram of the audio input circuits is given in figure 14-14. When the telegraph-phone switch is in the PHONE position, the grid of the tone oscillator is grounded and the grid of the microphone amplifier is ungrounded. If one then speaks into the microphone, an output voltage is developed across R1. This voltage is fed through C1 to the grid of V1. The lower audio frequencies are attenuated in C1, and the higher audio frequencies are shunted by C2. Actually, the whole system is designed to pass from 350 to 3000 cycles.

The microphone amplifier, V1, feeds the cathode follower, V2. Tube V2, in turn, feeds the input to the 1st balanced modulator.

When the telegraph-phone switch is in the TELEGRAPH position, the microphone output is shunted to ground, and the tone oscillator, V6, is connected to V1.

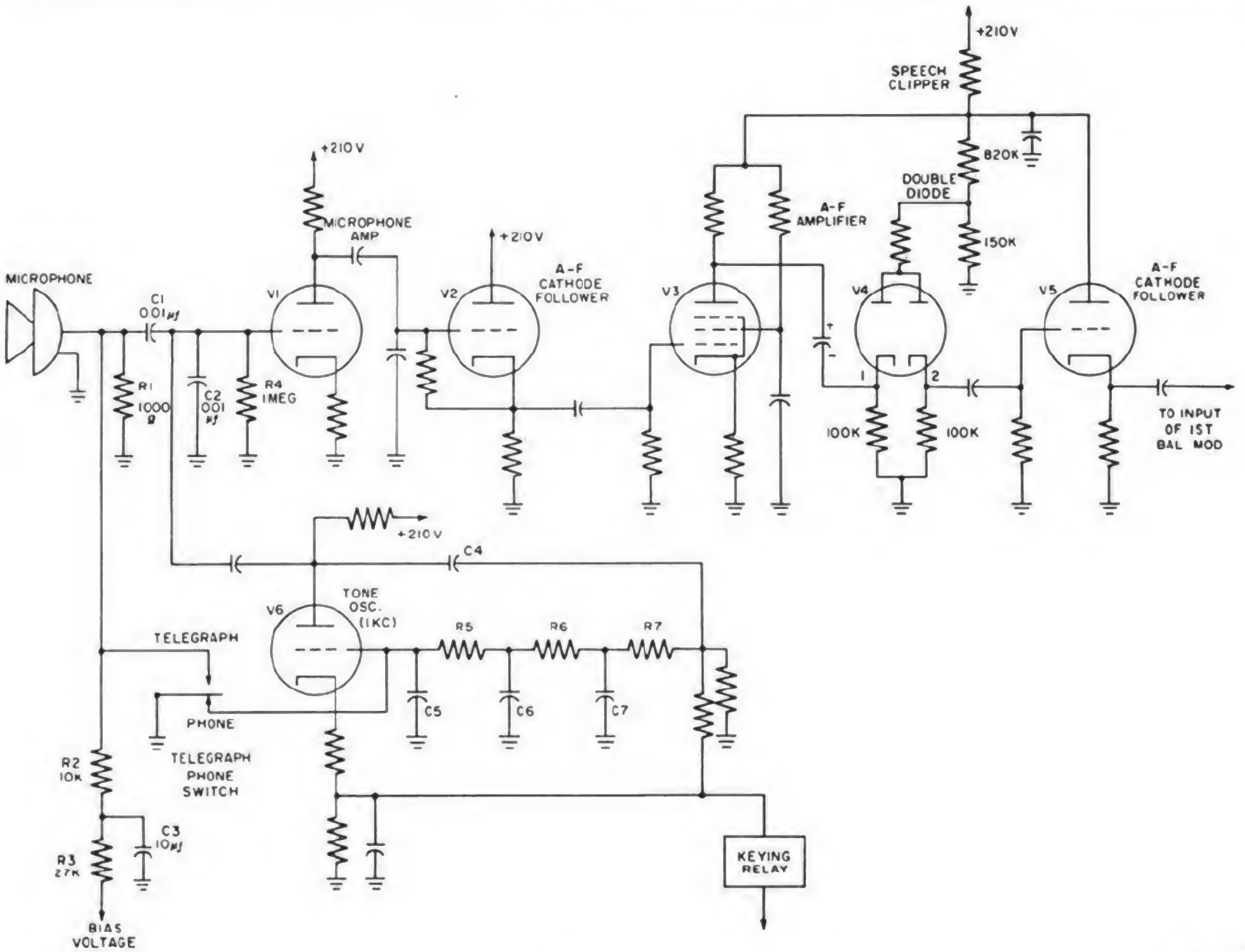

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Figure 14-14.—Audio input circuits.

The tone oscillator (phase-shift oscillator) provides the tone for telegraph work. A phase-shift oscillator may have any of four common circuit arrangements involving a network of resistors and capacitors or resistors and inductors coupling the plate circuit to the grid circuit. The arrangement shown in figure 14-14 is representative. In any case, the purpose of the network is to shift the phase of the signal voltage developed in the plate circuit 180° and to apply this voltage to the grid of the tube. In the circuit under consideration, the network, consisting of R7C7, R6C6, and R5C5, performs the phase-shift function.

The normal amplifying action of a tube introduces a 180° phase shift between the grid voltage and the plate voltage. The phase-shift network takes the signal from the plate and introduces an additional 180° phase shift and applies the signal as a positive feedback to the grid of the tube. Sustained oscillations at one specific frequency are thus obtained.

OUTPUT SECTION

The a-f signal from the first a-f amplifier, V16 (fig. 14-4) is fed through a transformer to the input of the second a-f amplifier (not shown). The amplified signal is then fed to the grid of the a-f output tube and the output of this tube is applied to the speaker. Feedback is used to improve the response.

LINEAR AMPLIFIERS

A linear amplifier is one that develops an output that is directly proportional to the

amplitude of the input signal. It is necessary to use linear amplifiers in a single-sideband transmitter in which low level modulation is used. The single-sideband system is an amplitude modulated system, and once the modulation is performed, the amplitude relationship must be faithfully maintained.

Non-linear characteristics of amplifiers, which are used after modulation of the signal, cause inter-modulation of separate frequency components in the signal. Some harmonics of the inter-modulation frequencies may be within the pass band of the system. These spurious signals cause noise and distortion of the intelligence signal. Inter-modulation frequencies near the pass band may also be of sufficient amplitude to cause noise and distortion in nearby bands. These spurious signals are particularly troublesome in two-channel, single-sideband systems.

Linear amplifier design is a problem when designing a single-sideband transmitter because it is necessary to produce a high power level to drive the antenna. The combination of high power gain and linear amplification is extremely difficult to achieve. Although linearity must be maintained in the amplifier stages of the single sideband exciter, the power level of the signals in the exciter are low. This low power level makes possible the use of receiving pentodes to obtain linear amplification with the desired gain in a minimum number of stages. Therefore, the r-f power amplifier is the most critical link between the generation of the single-sideband in the exciter and the signal that is finally transmitted in space.

Practical power amplifiers have been designed which raise the low power level signal of the exciter to the high level signal necessary at the antenna yet maintain the required linearity. However, if the input signal amplitude at the power amplifier becomes too great, the amplifier begins to operate on the non-linear portion of its input-output characteristic. To ensure that such overdriving does not take place, the output of the exciter is usually limited by the use of an AGC circuit. A portion of the exciter r-f output is rectified to provide a d-c voltage. This voltage is used to control the gain of one or more stages of the amplifier portion of the exciter.

A more detailed discussion of linear r-f power amplifiers, as used in transmitters, is included in Basic Electronics, NavPers 10087.

SSB TRANSCEIVER AN/URC-32

One of the Navy's most versatile modern communication equipments is the AN/URC-32 (fig. 14-15). It is a transceiver operating in the 2- to 30-mc range, with a transmitter peak envelope power (PEP) of 500 watts.

A transceiver, as you know, uses part of the same electronic circuitry for both transmitting and receiving, hence cannot transmit and receive simultaneously.

The AN/URC-32 is designed chiefly for single-sideband transmission, and for reception on either the upper or lower sidebands, or on both sidebands simultaneously, with separate audio and i-f channels for each sideband. In addition to single-sideband operation, provisions are included for a-m (carrier reinserted), CW, or FSK operation.

The frequency range of 2 to 30 mc is covered in four bands. The desired operating frequency is selected in 1-kc increments on a direct-reading frequency counter. Frequency accuracy and stability are controlled by a self-contained frequency standard.

AN/URC-32 BLOCK DIAGRAM

The transmitter of the AN/URC-32 (fig. 14-16) produces voice, CW, or FSK modulated signals on a single-sideband r-f carrier, or a compatible amplitude modulated r-f carrier.

Voice input signals from the dynamic handset are fed to the handset adapter. Input signals from a remote control unit also are applied to the handset adapter, permitting the operator to select either the local or remote audio input. Teletypewriter signals are applied directly to the CW and FSK unit, which provides separate audio tones for the mark and space conditions. These frequencies are later converted to the required frequency shift signals for FSK transmission.

The output from the handset adapter is amplified in the audio and control unit. Two separate audio input paths to the audio and control unit are provided through the 600-ohm remote audio lines.

The audio and control unit amplifies the audio signal and feeds it to the sideband generator. During single-sideband voice operation, the audio and control unit output is fed through a selector switch in the CW and FSK unit. For CW or FSK operation, the CW and FSK unit supplies audio tones to the sideband generator.

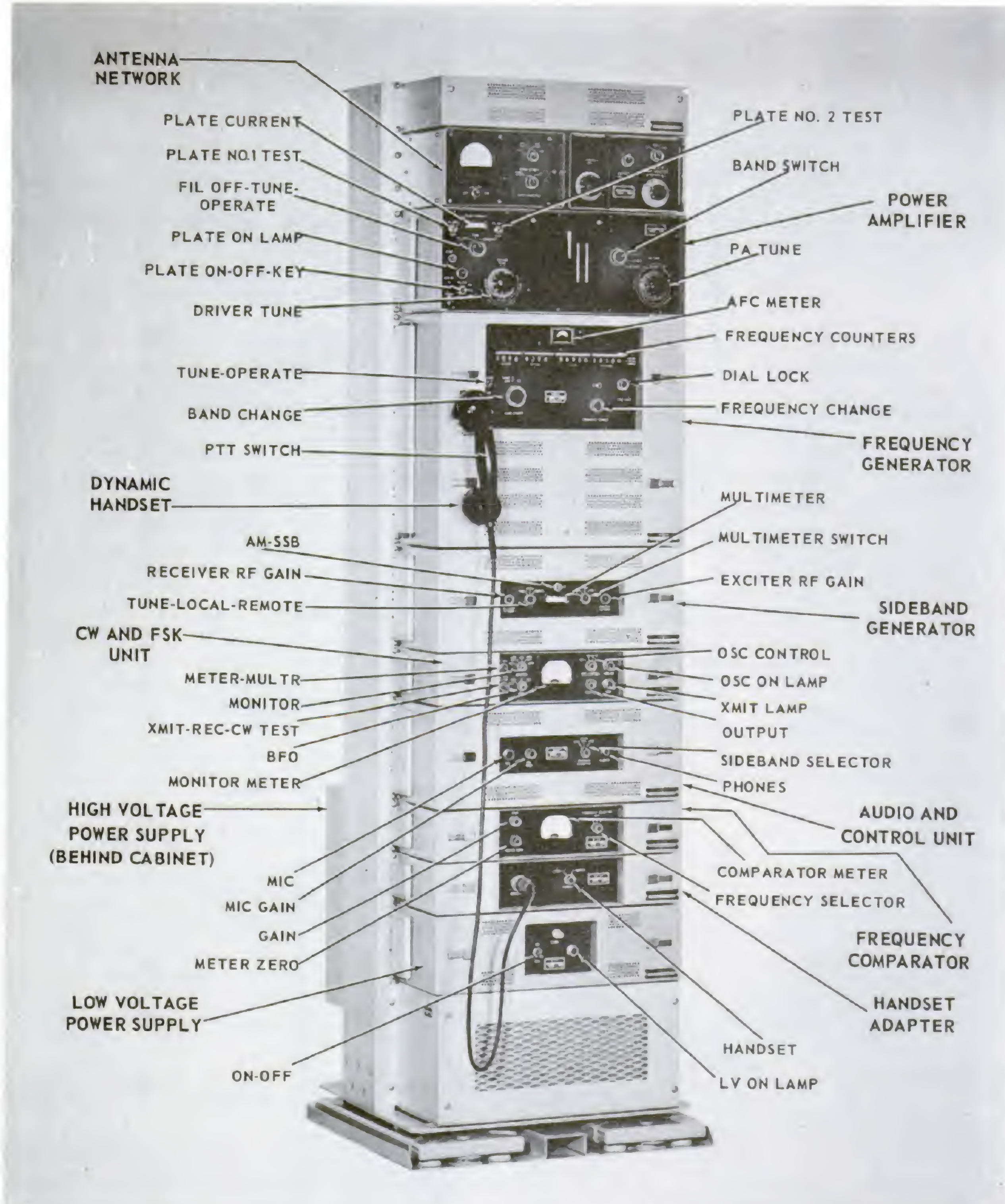

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Figure 14-15.—Radio Set AN/URC-32, relationship of units and operating controls.

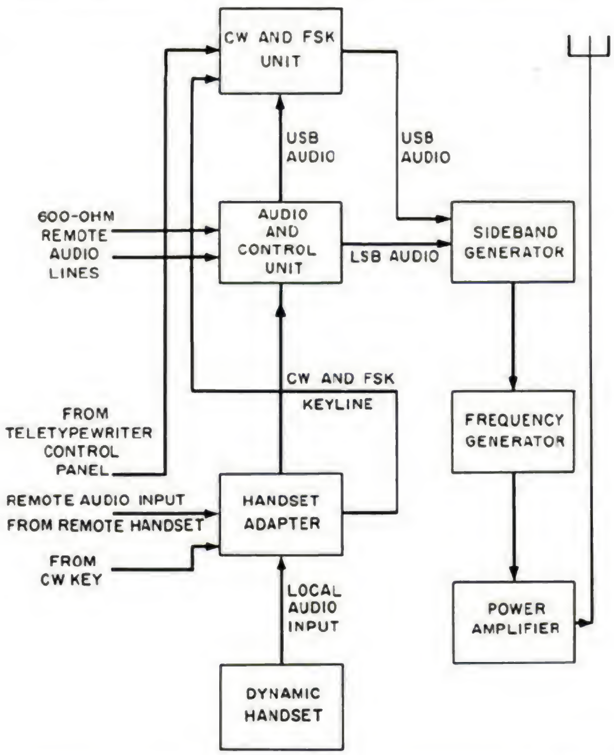

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Figure 14-16.—AN/URC-32, transmit function block diagram.

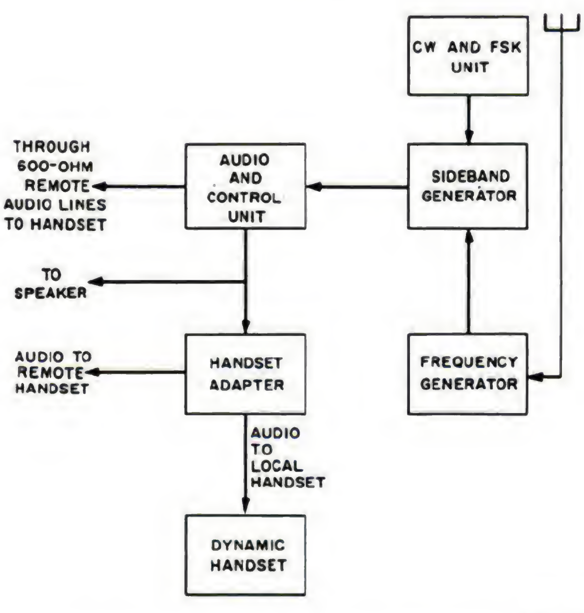

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Figure 14-17.—AN/URC-32, receive function, block diagram.

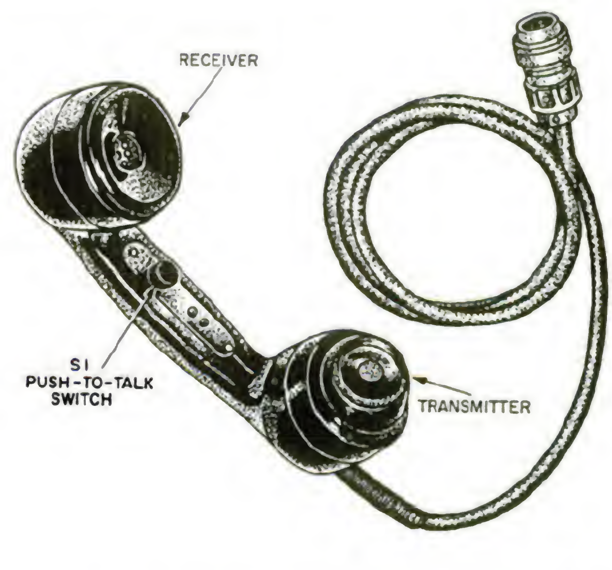
The sideband generator converts the audio input to the selected sideband of a 300 kc intermediate frequency. The modulated 300-kc output is fed to the frequency generator. This unit provides the necessary number of heterodyning processes (while preserving the signal intelligence) to produce the selected nominal carrier frequency in the 2- to 30-mc range. The output signal is amplified in the power amplifier to the required peak envelope power of 500 watts and fed to the antenna.

During receive operation (fig. 14-17) the antenna input signal in the range from 2 to 30 mc is heterodyned in the frequency generator so that the output will be a modulated 300-kc signal. This signal is detected and amplified in the sideband generator, further amplified in the audio and control unit, and fed to the speaker.

During CW reception, the CW and FSK unit supplies a 300.550-kc signal to the sideband generator as a beat frequency for the received signal. The beat frequency can be changed over a range of ± 1 kilocycle.

DYNAMIC HANDSET

The dynamic handset (fig. 14-18) consists of a noise-canceling dynamic microphone incorporating a transistor amplifier, a dynamic receiver, and a push-to-talk switch. The dynamic handset has the same plug-in connections, output



32.138
Figure 14-18.—Dynamic handset.

impedance, and output level as the Navy 51007A carbon handset, which makes these two units interchangeable. However, the dynamic handset provides improved audio quality over a carbon handset.

Both the transmitter and receiver are sealed plug-in-units. The transmitter contains the noise-cancelling dynamic microphone and the transistor amplifier. The receiver is a standard 600-ohm dynamic telephone receiver.

HANDSET ADAPTER

The handset adapter (fig. 14-19) permits local operation of the transmitter-receiver using the dynamic handset described above, or remote operation using a Radio Set Control C-1138/UR, and the Dynamic Handset AN/URC-32. Local or remote operation is selected by the handset control on the front panel. A connector on the front panel is provided for the handset.

In the LOCAL position, handset switch S1 (fig. 14-20) connects the audio output from the receiver (terminals 5 and 6) to the handset (terminals A and B), and connects the audio output from the handset transmitter to the system transmitter. Also, in local operation, the key line is connected to contact 4 of relay K1. Contacts 4 and 3 of K1 are open (as shown) for receive operation. When the handset push-to-talk button is depressed, relay K1 energizes, and contacts 4 and 3 close to apply a ground to the key line. This, in turn, operates the various control circuits of the transmitter.

A 12-volt power source supplies power for K1 and the handset microphone. This supply uses transformer T1 and rectifiers CR1-CR4 in a fullwave dry-disc bridge rectifier circuit.

In the REMOTE position, handset switch S1 connects the audio output from the receiver to the remote control circuits, and also connects the audio output from the remote control circuit to the transmitter. In remote operation, the key line and 12 volts from the handset adapter power supply are connected to the remote controls.

AUDIO AND CONTROL UNIT

The audio and control unit (fig. 14-21) is a dual-channel amplifier, which can provide audio inputs from two 600-ohm balanced lines, a 600-ohm unbalanced line, or a high-impedance microphone. In the normal AN/URC-32 installation, the 600-ohm balanced lines and the dynamic microphone input are not used.

On transmit, when using the 600-ohm unbalanced input, the audio signal from the handset adapter is fed to the audio and control unit via audio transformer T6 (fig. 14-22). This input, after amplification, can be applied to the upper sideband line amplifier or to the lower sideband line amplifier in the audio and control unit.

The sideband selector switch controls the signal transmission and reception. With the switch in the OFF position, the microphone amplifier circuits and the remote audio input are disconnected from the line amplifiers. This also connects the upper and lower sideband 600-ohm audio line inputs to the line amplifiers.

With the sideband selector switch in the UPPER position, the microphone audio or remote audio is fed into the upper sideband line amplifier. This also selects the upper sideband audio output from the sideband generator and applies it to the speaker amplifier circuits.

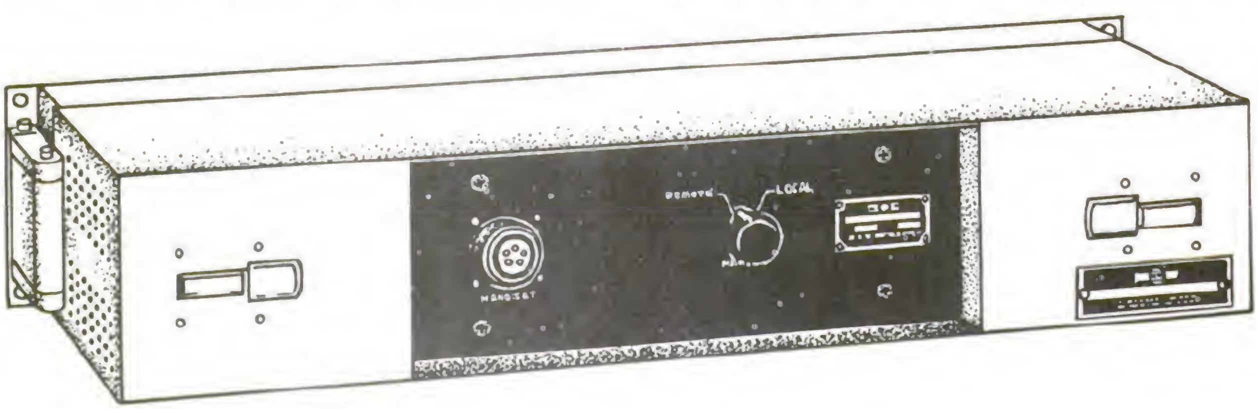


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Figure 14-19.—Handset adapter.

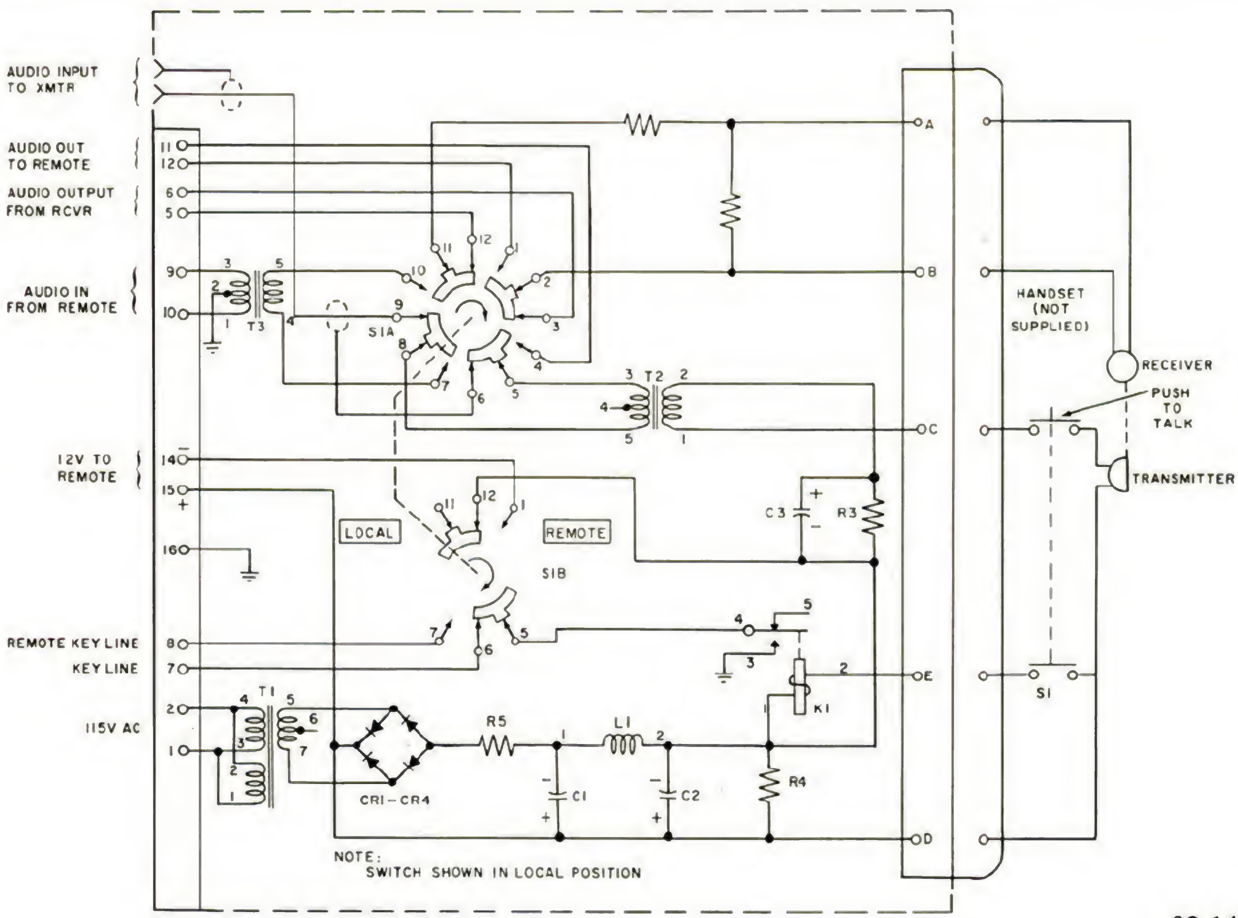

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Figure 14-20.—Handset adapter, schematic diagram.

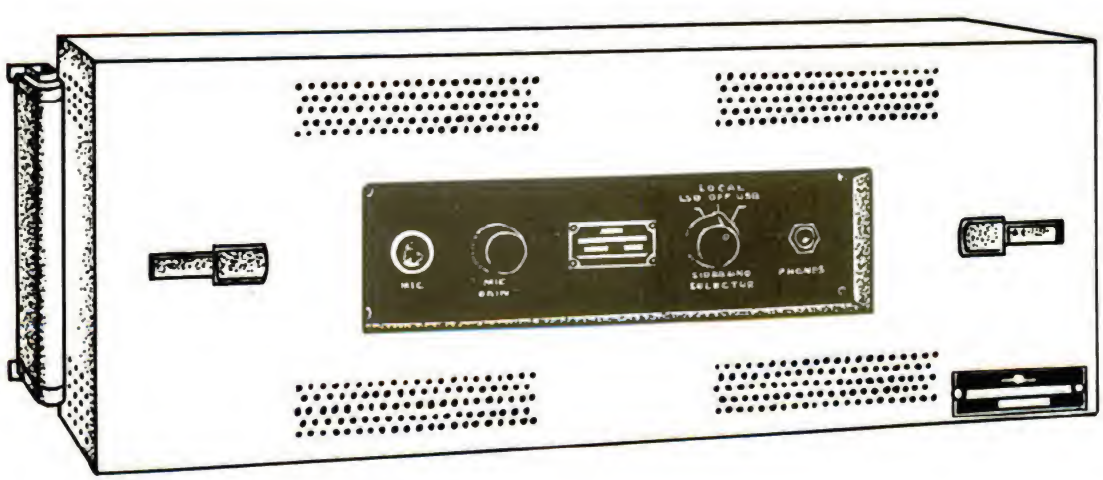

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Figure 14-21.—Audio and control unit.

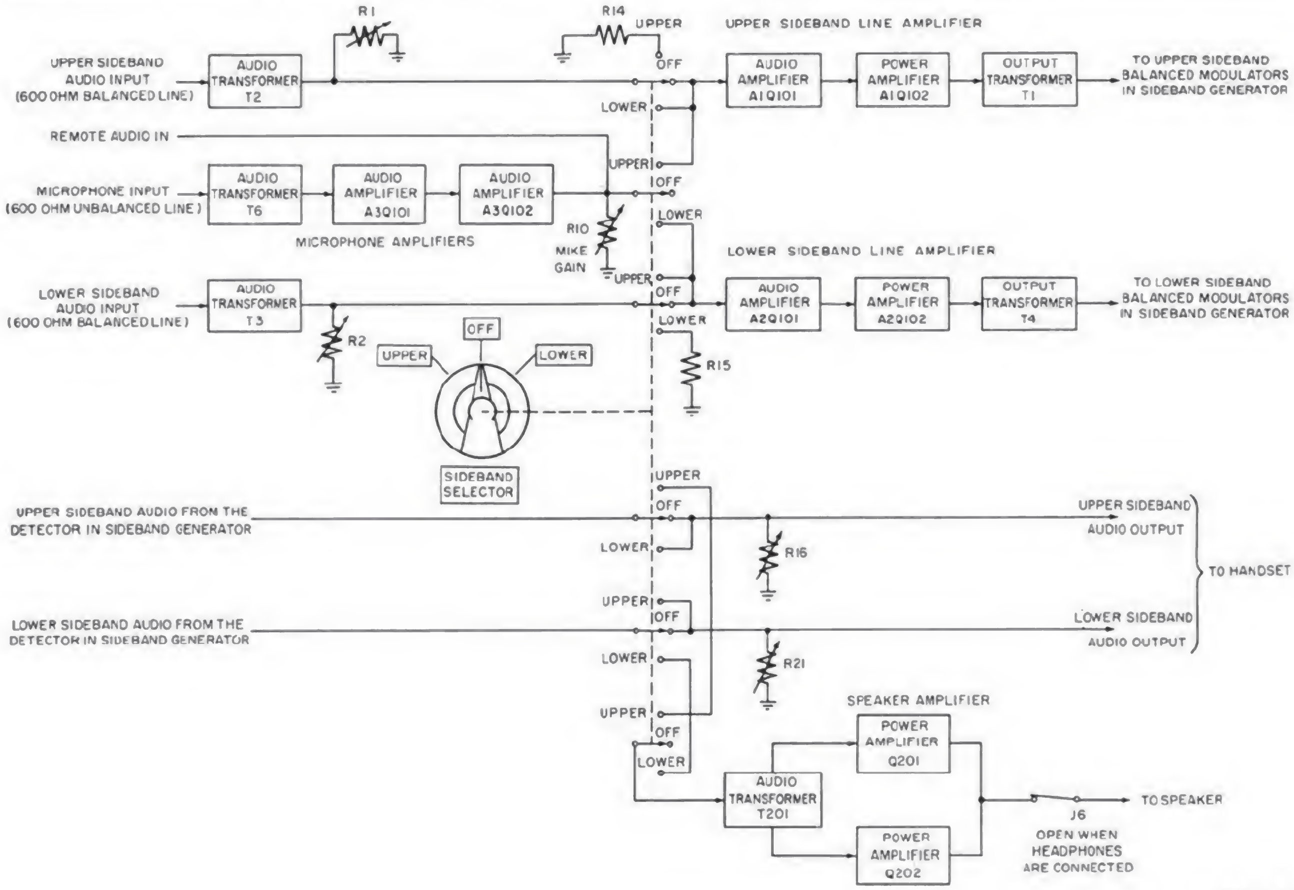

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Figure 14-22.—Audio and control unit, block diagram.

The reverse of this action happens when the sideband selector is placed in the LOWER position. When earphones (not shown) are plugged into the phone jack on the front panel (fig. 14-21) the audio output normally fed to the speaker is removed.

The upper and lower sideband line amplifiers (fig. 14-22) are controlled by the upper and lower sideband audio inputs. With the sideband selector switch in the OFF position, the two sideband amplifiers can be used either individually or simultaneously.

Assume the audio input is on the upper sideband. This input is coupled by audio transformer T2 and the sideband selector switch (in the OFF position) to the first upper sideband line amplifier A1Q101 for amplification. The amplified output of A1Q101 is coupled to the power amplifier A1Q102 for further amplification. The output is fed via T1 to the upper sideband balanced modulator in the sideband generator. The gain of the sideband line amplifier is controlled by attenuator R1. Operation of both the upper and lower sideband line amplifiers is the same.

When the sideband selector switch is in the UPPER position, the upper sideband audio is removed from the audio amplifier A1Q101 and is correctly terminated by R14. Either the microphone amplifier circuit or the remote audio is then connected to the audio amplifier A1Q101.

With the sideband selector switch in the LOWER position, the lower sideband audio is removed from A2Q101 and correctly terminated by R15. The microphone amplifier circuits are then connected to the audio amplifier A2Q101.

SIDEBAND GENERATOR

The sideband generator (fig. 14-23) translates audio frequencies to intermediate

frequencies during transmit condition, and intermediate frequencies to audio frequencies during receive condition.

Transmit Function

The block diagram of the sideband generator is shown in figure 14-24. The balanced modulator, carrier generator, and transmitter gain control (TGC) operate during transmit condition. The audio input to the sideband generator is taken from the audio and control unit (fig. 14-22) and applied to the sideband generator via T3 and T4. Audio input transformers T3 and T4 (fig. 14-24) couple the upper sideband and lower sideband audio inputs to the balanced modulators.

The balanced modulators modulate a 300-kc carrier to produce separate and distinct upper and lower sideband signals with the carrier suppressed. The 300-kc carrier is produced in the carrier generator by tripling the 100-kc reference oscillator signal from the frequency generator (discussed later).

The balanced modulator contains two 300-kc balanced modulators. Because of a frequency inversion in the r-f tuner, the lower sideband balanced modulator is followed with an upper sideband filter, and the upper sideband balanced modulator is followed with a lower sideband filter. The inversion process which takes place in the r-f tuner is explained later.

The outputs of the balanced modulator are connected in parallel and fed to the transmitter gain control. The TGC circuit is controlled by a TGC voltage, which is received from the power amplifier unit. This circuit maintains the 300-kc i-f output voltage at a sufficiently low level to prevent overdriving any of the subsequent stages.

The 300-kc SSB signals are fed via line TX to the r-f tuner and power amplifier (described later). During tune and a-m transmit conditions only, the unmodulated 300-kc carrier generator output is reinserted in the upper sideband signal at the inputs of V1A in the r-f tuner. Reinsertion of the carrier at the transmitter eliminates reinsertion at the receiver and the necessity for having special equipment to receive the transmitted signal. The absence of the lower sideband does not affect the quality of the received signal. However, only one sideband plus carrier is transmitted, and the received signal is considerably stronger than it would be for double-sideband a-m operation.

Receive Function

The i-f and audio amplifiers (lower sideband, upper sideband, and a-m) operate only during the receive condition to amplify the modulated 300-kc i-f signal from the r-f tuner (via line RX). These units also demodulate the signal and amplify the detected audio. A 300-kc

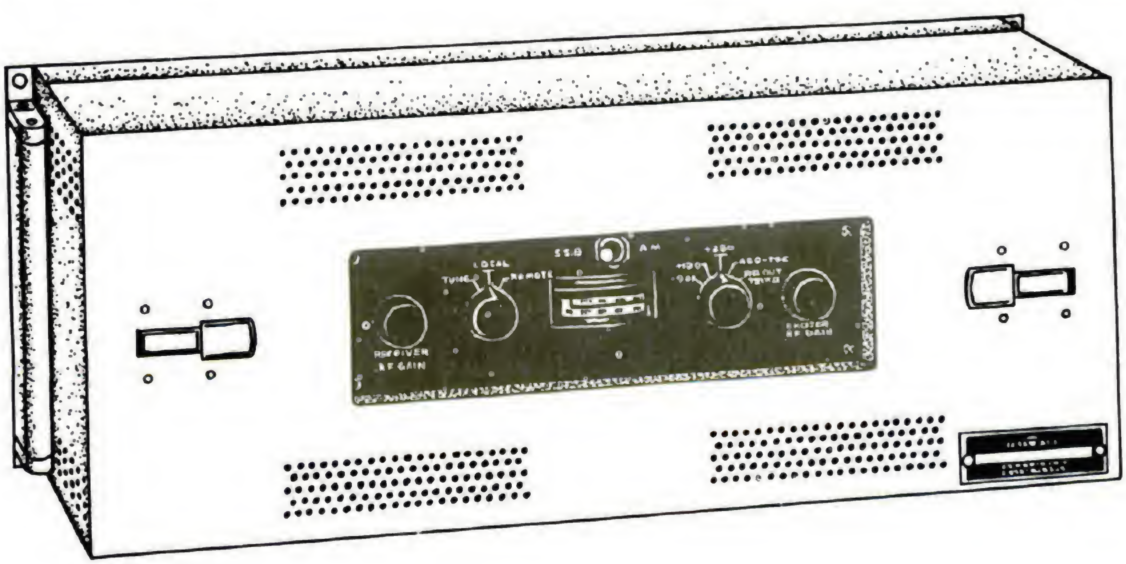

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Figure 14-23.—Sideband generator.

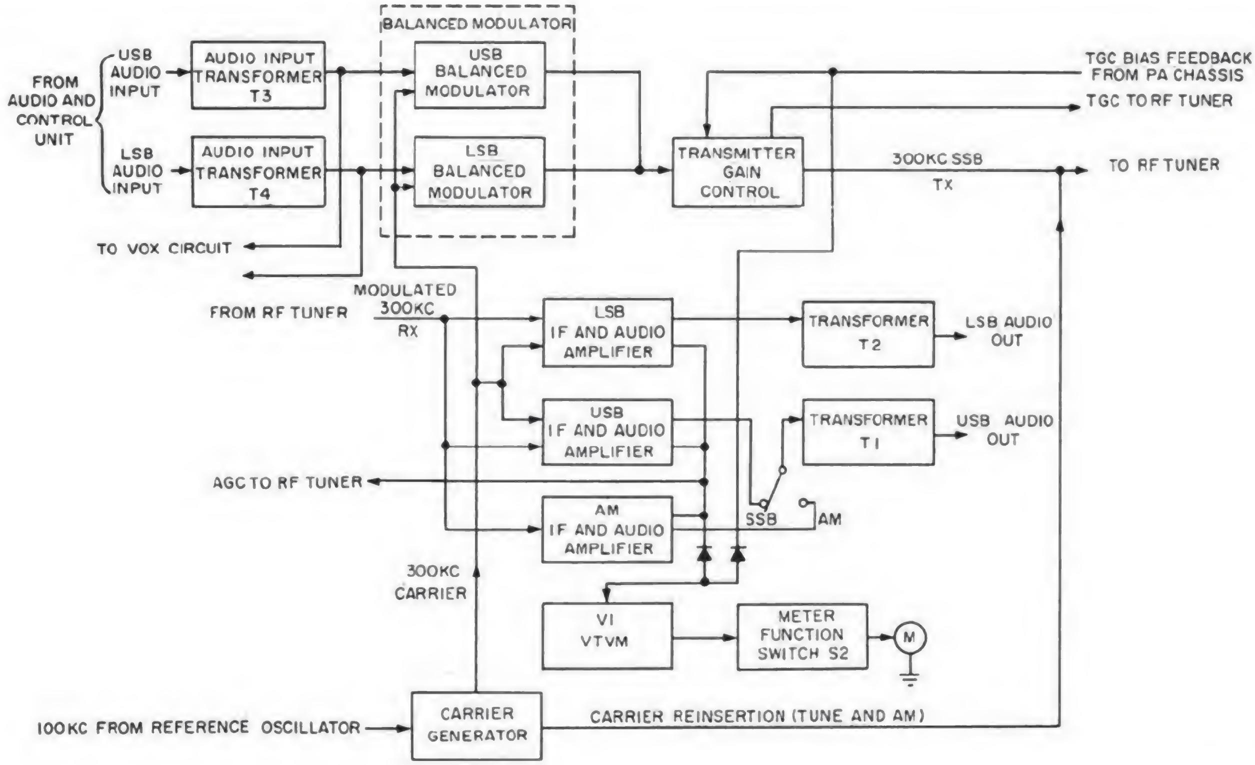

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Figure 14-24.—Sideband generator, block diagram.

carrier is reinserted into the lower sideband and upper sideband i-f/a-f amplifiers from the carrier generator.

When the front panel SSB a-m switch is in the a-m position, the lower sideband and upper sideband i-f/a-f amplifiers are disabled. The carrier generator (a-m receive only) also is disabled, as will be shown later. The audio output from the a-m i-f/a-f amplifier is fed through the SSB a-m position to the upper sideband audio out lines via transformer T1. The a-m i-f/a-f amplifier is disabled when the SSB a-m switch is in the SSB position.

CW AND FSK UNIT

The CW and FSK unit (fig. 14-25) enables the AN/URC-32 transceiver to be operated in the CW and FSK modes of operation. On FSK transmit operation (tone modulation), the CW and FSK unit converts the keying input from a teletypewriter current loop to audio tones of 1575 cps for space (no loop current) and 2425 cps for mark (loop current). On CW transmit operation the unit provides a keyed audio tone of 1000 cps or 1500 cps as selected by the OSC control switch on the front panel.

During FSK receive operation, the CW and FSK unit provides a bfo (beat-frequency oscillator) signal required for FSK reception. This signal is centered on 300.550 kc, and is variable approximately 1 kc above or below this frequency. This raises the space and mark tones 550 cps to make the AN/URC-32 compatible with other teletypewriter terminal equipments.

The CW and FSK unit (fig. 14-26) consists of (1) an oscillator-buffer-amplifier (V1A, V1B, and V2A), (2) a bfo (Q1), (3) a CW break-in relay and relay amplifier (V2B), and (4) a monitor circuit (via S2). The monitoring circuit contains a meter M1, which is used for monitoring the receive and transmit audio outputs of the audio and control unit, and for monitoring the output of the CW and FSK unit.

The function of the CW and FSK unit is determined by the position of the oscillator

control switch S1 located on the front panel. In the OFF position, S1C disables the CW and FSK unit by removing the B+ voltage (+130 v) from the circuits. Also, in this position, S1E connects the upper sideband transmit audio input line from the audio and control unit to the upper sideband transmit audio output line connected to the upper sideband balanced modulators of the sideband generator. Thus, in the OFF position, the CW and FSK unit circuits (fig. 14-26) are deenergized, and the voice input signals from the handset are transmitted.

When S1 is moved one position (from the position shown), FSK signals are transmitted. In the final two positions of S1, CW signals are transmitted.

During FSK and CW operation, the upper sideband transmit audio input line from the audio and control unit is disconnected, and the output of the oscillator-buffer-amplifier circuit is connected to the upper sideband transmit audio output line. In the FSK position, the frequency of the oscillator V1A is shifted from 1575 cps for space to 2425 cps for mark by the teletypewriter loop input.

In the CW positions, the oscillator frequency is 1000 cps (corresponding to the 1-kc position) or 1500 cps (corresponding to the 1.5-kc position), depending on the setting of oscillator control switch S1 on the front panel. Buffer stage V1B permits passage of the V1A oscillator output when the CW and FSK key line is completed to ground.

CW and FSK Oscillator

The oscillator V1A frequency is adjusted, as determined by the mode of operation, by changing the components in the grid-cathode tank circuit. With S1B in the FSK position, the tuned circuit of oscillator V1A consists of L1, C3 and the capacitors in the FSK circuit. The teletypewriter input signal at pin 1 of J1 determines which capacitors of the FSK keying circuit are inserted in the tuned circuit, and therefore determines the frequency of the oscillator.

The FSK keying input circuit has a relatively high impedance. Therefore, if the CW and FSK unit is to be used with a teletypewriter operating on a standard loop current, an external resistor of approximately 800 ohms or larger should be placed across the signal line to permit the 20-, 30-, or 60-ma loop current to develop a positive voltage pulse of 25 to 50 volts at the input terminal.

With no current in the teletypewriter loop (corresponding to space condition), voltage divider R11 and the teletypewriter terminating resistor in parallel with R12 applies a negative voltage across CR2 and CR3 from the -90 volt bias line. This causes CR2 and CR3 to conduct. With CR2 and CR3 conducting, C4 and C5 are placed in the tuned circuit of the oscillator in parallel with C6 and C7. This action produces an oscillator output frequency from V1A of 1575 cps, which represents the space condition FSK output frequency.

When a mark current is present in the teletypewriter loop, a positive voltage is developed across the external resistor in parallel with R12. This voltage exceeds the negative voltage which appears across R12 and the external resistor during the space condition, and the direction of current through these resistors changes direction from downward through the resistors to upward.

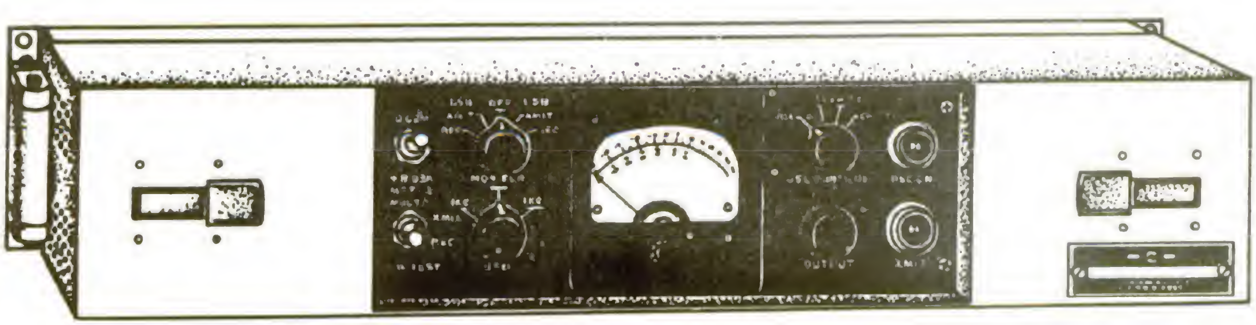

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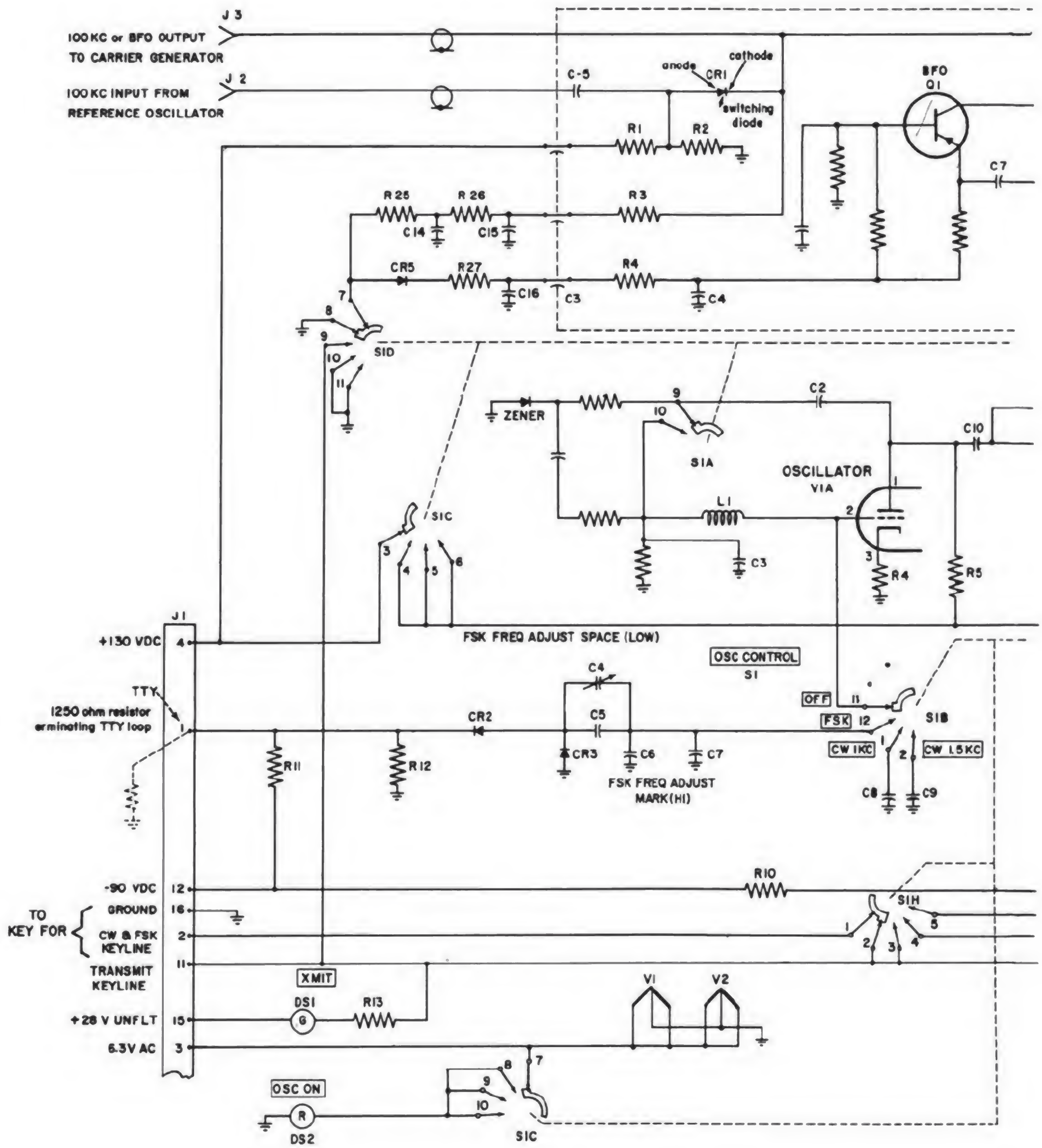
Figure 14-25.—CW and FSK unit.


J 3
100 KC or BFO OUTPUT
TO CARRIER GENERATOR
J 2
100 KC INPUT FROM
REFERENCE OSCILLATOR
C-5
anode
CR1
cathode
switching
diode
R1
R2
BFO
Q1
C7
R 25
R 26
R3
C14
C15
CR5
R27
R4
C16
C3
C4
7
8
9
10
11
SID
C2
ZENER
9
10
S1A
C10
OSCILLATOR
V1A
L1
2
3
C3
R4
R5
S1C
3
4
5
6
J1
+130 VDC
4
FSK FREQ ADJUST SPACE (LOW)
OSC CONTROL
S1
TTY
1250 ohm resistor
erminating TTY loop
1
CR2
C4
C5
OFF
11
FSK
12
S1B
CW 1KC
CW 1.5KC
1
2
CR3
C6
C7
R11
R12
FSK FREQ ADJUST
MARK (HI)
C8
C9
-90 VDC
12
R10
GROUND
16
S1H
TO
KEY FOR
CW & FSK
KEYLINE
2
1
2
3
4
5
TRANSMIT
KEYLINE
11
XMIT
DS1
R13
V1
V2
+28 V UNFLT
15
G
6.3V AC
3
8
7
9
10
OSC ON
R
DS2
S1C

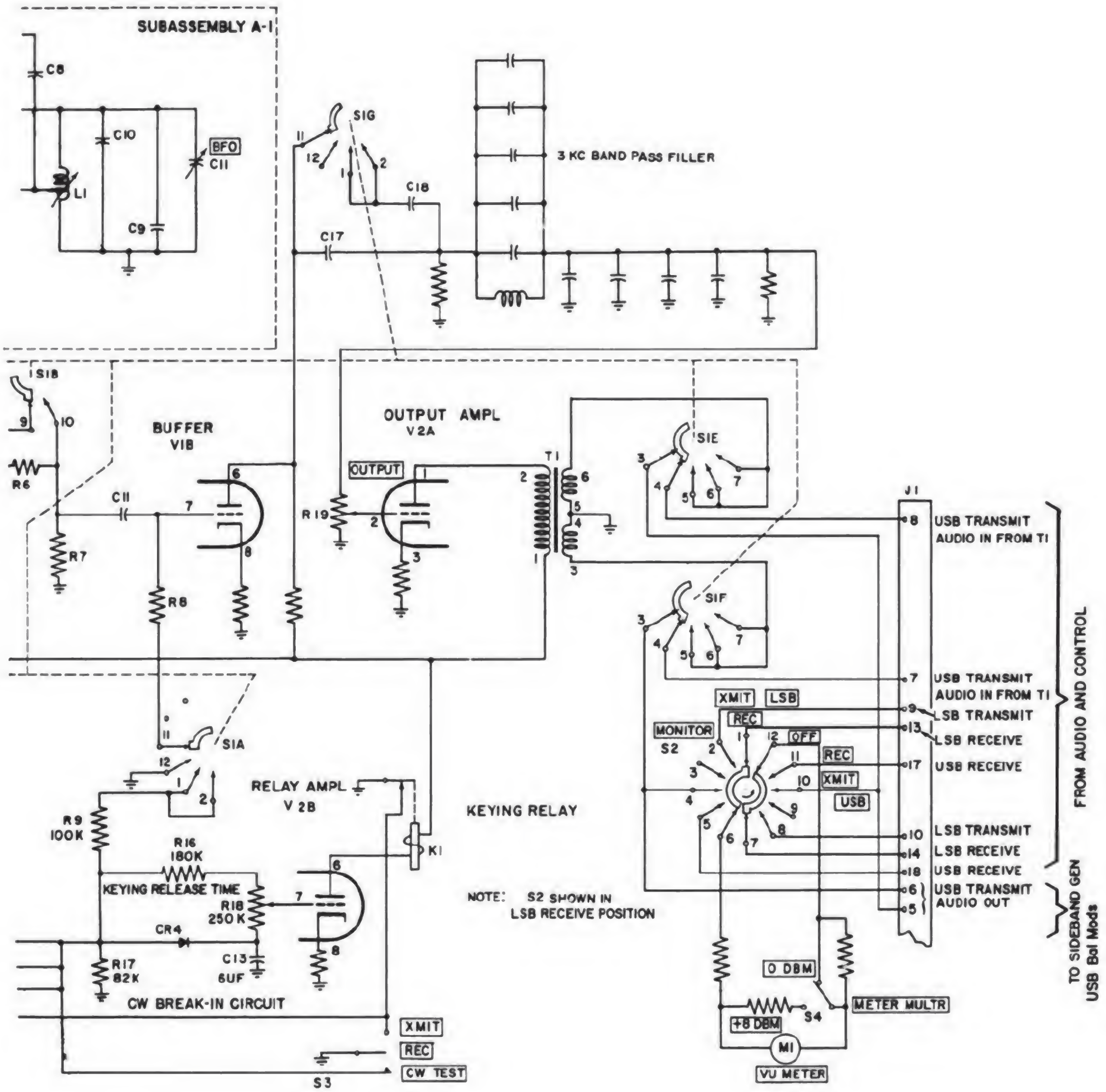


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Figure 14-26.—CW and FSK unit, schematic diagram.

The resulting positive voltage at the R12-CR2 junction cuts off CR2 and CR3, and effectively removes C4 and C5 from the tuned circuit of the oscillator. The oscillator frequency changes to a higher frequency (as a result of the decrease in capacitance) to produce 2425 cps. This frequency corresponds to the mark condition of the FSK output. The oscillator signal is fed through the buffer V1B the output amplifier V2A, S1E, and S1F, to the upper sideband transmit audio output lines.

In the CW 1-kc position of S1, section S1B removes the capacitors in the FSK keying input circuit and inserts C8 in the oscillator tank. This tunes the oscillator to 1 kc. In the CW 1.5-kc position, C9 is connected in the oscillator tank circuit to tune the oscillator to 1.5-kc.

Buffer and Output Amplifier

The output of the oscillator V1A is fed to the grid of buffer V1B. In the FSK position (12), S1A applies a ground to grid resistor R8, and the buffer stage functions continuously. In the two CW positions (1 and 2) of S1A, the buffer (V1B) is biased to cutoff. The cutoff voltage is applied to the V1B grid through R8 and R9 from the junction of R10 and R17, which are connected from the -90 volt supply to ground. The buffer is keyed by the CW and FSK line, which applies a ground (when closed) to the junction of R10 and R17 through contacts 1 and 4 (or 5) or S1D. Thus, closing the CW key removes the bias from the buffer stage, and V1B passes the oscillator (V1A) output.

The V1B output is fed through a bandpass filter which rejects 3 kc. On CW operation, C18 is connected in the filter input path by S1G in parallel with C17, and the filter attenuates the second harmonic of 1.5 kc and the third harmonic of 1 kc. During FSK operation (position 12), S1G removes C18 from the filter input circuit, and the second harmonic of the 1575-cps space frequency is attenuated.

The filtered output from V1B is developed across output control R19. The T1 secondary provides a 600-ohm balanced output (CT grounded) via S1F and S1E (CW and FSK positions 5, 6, and 7) to the upper sideband audio output line. In the OFF position (as shown), S1E connects the upper sideband transmit audio input line directly to the upper sideband transmit audio output line.

CW Break-In Relay Circuit

The CW break-in relay circuit, comprising relay amplifier V2B and keying relay K1, applies a ground to the transmit key line via pin 2 and pin 16 of J1 when the CW key is closed, and maintains this ground via pin 11 of J1 through the normal CW key open intervals of a CW transmission. In the two CW positions, S1H (pins 4 and 5) connects the CW and FSK key line through R16 and R18 to the grid of relay amplifier V2B. The plate circuit relay K1 operates on a fast response and a delayed release principle. This is accomplished by controlling the grid voltage of V2B from two RC circuits, one with a short time-constant, and one with a long time-constant.

In the initial key-up condition, C13 charges to approximately -20 volts through R10, R16, and R18, from the -90 volt supply. The voltage across C13 maintains V2B in cutoff, and K1 is deenergized.

When the CW key is closed, a ground is applied to the CW and FSK key line and C13 is discharged through the small forward resistance of CR4, pins 4 or 5 of S1H, the key and ground, or via pins 2 and 16 of J1. This represents a short time-constant as compared to the charge path through R16 and R18. The discharge of C13 removes the negative bias voltage from the grid of V2B, the tube conducts, and K1 is energized, thereby placing a ground on the transmit key line via pin 11 of J1.

When the CW key is opened, the ground is removed from the CW and FSK key line, and C13 is charged through the high resistance of R16 and R18. When the voltage at the tap of R18 reaches the cutoff value of V2B, K1 is deenergized and ground is removed from the transmit key line.

The long time-constant of R10, R16, R18, and C13 provides the time delay necessary to maintain the transceiver in the transmit condition during the normal key-open interval of a CW transmission. When S1D is in the OFF or FSK position (1, 2, or 3), the CW and FSK key line is connected directly through contacts 1 and 2 (or 3) to the transmit key line. The CW and FSK key line can then be used as a remote transmit key line.

BEAT-FREQUENCY OSCILLATOR

The beat-frequency oscillator (bfo) circuit consists of transistor oscillator Q1 and a

switching diode CR1, which disconnects the 100-kc input signal at J2 from the 100-kc output signal jack J3 on FSK receive operation. During all modes of operation except FSK receive, the 100-kc signal input from the reference oscillator at J2 (discussed later) is fed through J3 to the carrier generator, where it is multiplied to produce the 300-kc i-f signal. Diode CR1 is maintained in a conducting state by a bias voltage obtained from the voltage divider comprising R1 and R2 across the +130 volt supply. In the OFF and CW positions of S1, S1D completes the d-c path through CR1 from ground contacts 8 and 7 of S1D, R25, R26, R3, CR1, and R1 to the +130 volt supply.

Because the peak amplitude of the 100-kc input signal at J2 is smaller than the voltage from the C5-CR1 junction to ground, CR1 remains conducting during the application of the complete 100-kc sine wave signals. The output voltage variations from CR1 are developed across R3, R25, and R26. The 100-kc input from J2 is fed via J3 to the carrier generator for all modes of operation except FSK receive.

During FSK transmit condition, the ground on the CR1 anode is completed through contacts 7 and 9 of S1D when the transmit key line is closed. Thus, during FSK transmit, the 100-kc signal is coupled through CR1 to the carrier generator, and the 300-kc i-f signal is produced in the normal manner.

During FSK receive operation, +28 volts d-c is applied to the transmit key line through indicator lamp DS1, R13, and the relay solenoids connected to the key line in other units. This positive potential is applied through contacts 9 and 7 of S1D, R25, R26, and R3, to the cathode of CR1. Because this potential is more positive than the positive voltage applied to the anode of CR1, the diode cuts off during FSK receive operation, thereby disconnecting J2 from J3.

The positive voltage on the transmit key line is fed through CR5 and a filter comprising R27, C16, R4, and C4, to bfo circuit Q1. This action energizes the bfo.

The frequency of the bfo circuit is determined by parallel resonant tank circuit L1 and C9, C10, and C11 in the collector circuit. The feedback signal from the L1 tap to ground is coupled through C7 to increase emitter forward bias current when collector current is increasing. When Q1 saturates, the feedback potential from L1 drops momentarily to zero. As forward bias decreases, collector current decreases, and the feedback from the L1 tank decreases the base-emitter current. This action sustains oscillation in the tank circuit. Inducter L1 can be adjusted for a center frequency of 300.550 kc. Capacitor C11 provides a method of varying the frequency approximately 1 kc above or below the center frequency.

The output signal from the bfo is taken from the tap on L1 and fed through C8 to the output jack J3. This signal is amplified in the carrier generator and used as a beat-frequency signal with the received FSK signals.

CONTROL CIRCUITS

The AN/URC-32 is keyed to transmit by applying a ground to a transmit key line. The method by which this ground is supplied to the transmit key line depends upon the mode of operation and the position of the handset switch on the handset adapter and OSC control switch on the CW and FSK unit.

During voice operation, the OSC control switch is set to OFF. This deenergizes the CW and FSK unit circuits and connects the transmit key line to the handset switch. When the handset switch is in the LOCAL position, a ground is applied to the transmit key line by a relay in the handset adapter. The relay (K1 in the handset adapter) is energized when the push-to-talk button on the local handset is depressed. This action closes the K1 contacts to ground the transmit key line.

When the handset switch is in the REMOTE position, the transmit key line is connected to the remote key line. The ground is supplied to the line by a push-to-talk relay in the remote phone unit.

For FSK operation, the OSC control switch (on the CW and FSK unit) is set to the FSK position and the handset switch is set to REMOTE. This energizes the FSK circuits of the CW and FSK unit, and connects the transmit key line to the remote key line. A ground is then applied to the remote key line at the teletypewriter control panel.

For CW operation, the OSC control switch S1 (fig. 14-27) is set to either the CW 1-kc or the CW 1.5-kc position, and the handset switch is set to REMOTE. This action applies B+ to the CW circuits of the CW and FSK unit, and connects the remote key line to the CW key line of the CW and FSK unit. The remote key line becomes a CW key input, and is grounded by the CW key.

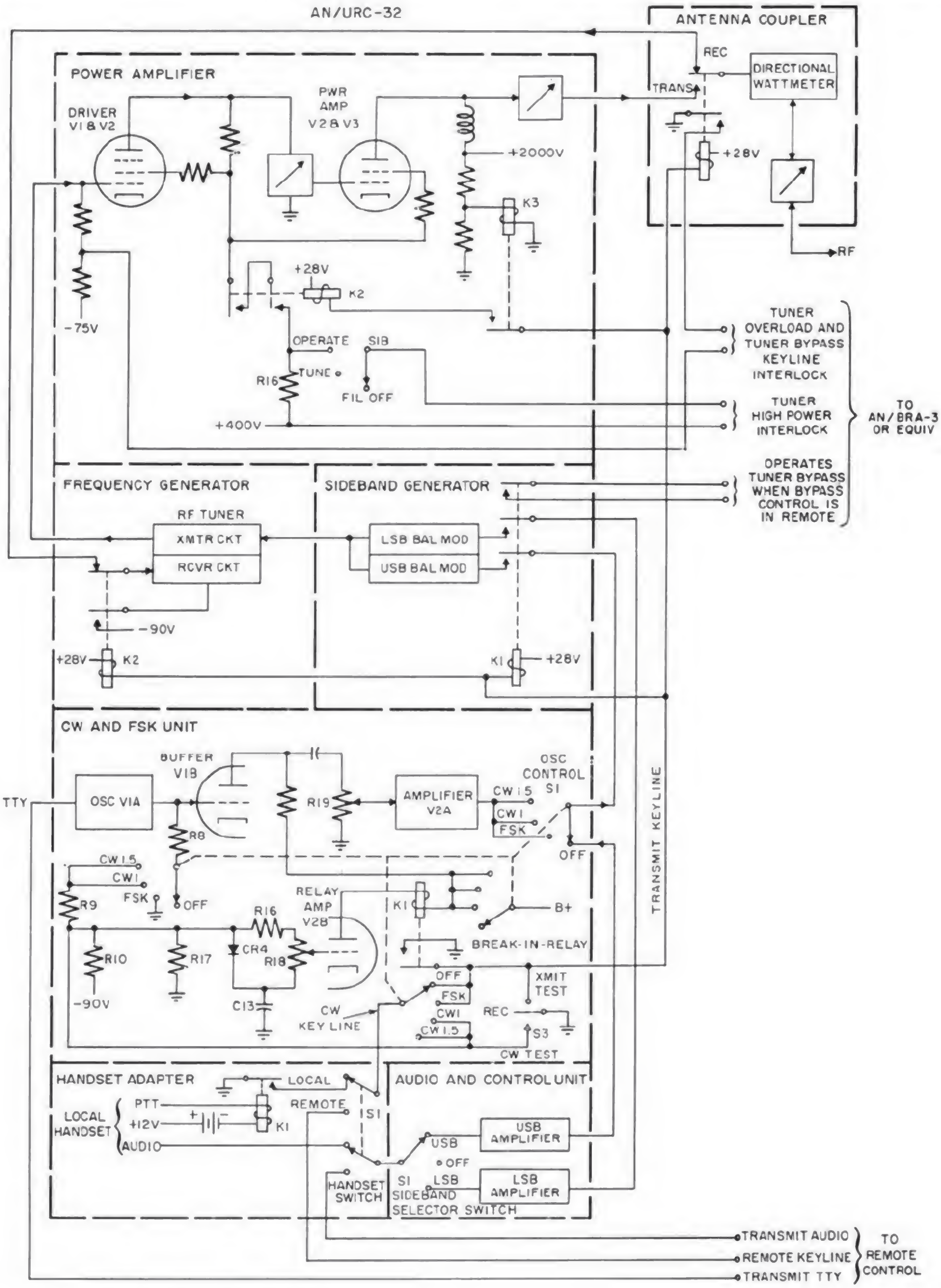

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Figure 14-27.—Transmit control circuit.

When the CW key is open, the grid of buffer stage V1B is blocked by a high negative potential. When the key is closed, the V1B negative grid bias is reduced and the oscillator signal from V1A is allowed to pass. With V2B conducting, the break-in relay K1 is energized to apply a ground to the transmit key line. This action keys the transmitter carrier.

The break-in relay K1 incorporates a delay circuit, which holds the transceiver in transmit operation during normal CW key-open intervals. When K1 in the CW and FSK unit is deenergized, the ground for the transmit key line is removed by the K1 contacts.

Grounding the key line energizes the receive-transmit relays of the AN/URC-32 and the antenna coupler. When transmitting, K1 in the sideband generator applies the transmit audio signals to the balanced modulator via oscillator control S1 in the OFF position. The relay also closes the contacts that operate an antenna bypass circuit in a remote antenna tuner (such as the AN/BRA-3) when different transmitting and receiving frequencies are utilized (cross-band operation). A separate receiver unit must be used during crossband operation.

With the antenna tuner bypass switch in the REMOTE position (not shown), the antenna tuner is bypassed when the relay contacts are open (receive condition). When crossband operation is not being used, the bypass switch in the antenna tuner should be in the TUNER-IN position to decrease the transmit keying time. Transmit keying time increases during cross-band operation because the transmit keying circuit is interlocked through the antenna tuner bypass circuit so that the AN/URC-32 is not keyed to transmit until the tuner bypass circuit of the remote antenna tuner switches from the BYPASS to the TUNER-IN position. When CW keying is used in the AN/URC-32, this time lag may result in a partial loss of the first character of the code transmissions.

In the transmit condition, K2 in the frequency generator disables the receiver circuit of the r-f tuner. This is accomplished by applying a cutoff bias voltage to the grids of the receiver stages and by disconnecting the receiver input from the antenna to the r-f tuner. Relay K2 in the power amplifier applies voltage to the driver screens and plates and to the power amplifier screens. This relay is interlocked through contacts of relay K3, which prevents the operation of K2 when the power amplifier plate voltage is not applied.

The output level of the power amplifier is controlled by the tune-operate switch S1B. This switch controls the driver plate and screen voltage and the power amplifier screen voltage by inserting a dropping resistor R16 in the 400-volt supply line during the tune or low level condition of the transmitter. For high power operation, this resistor is shorted out through tune-operate switch S1B and the tuner high power interlock (not shown). The antenna tuner high power interlock prevents high power operation when the antenna tuner is not tuned to the operating frequency.

The relay in the antenna coupler switches from the receiver input circuit in the frequency generator to the transmitter output circuit of the power amplifier. Auxiliary contacts on the relay apply a ground through an antenna bypass interlock to remove the disabling bias applied to the driver grids of the power amplifier unit during transmission. The antenna bypass interlock prevents r-f drive power from being applied to the power amplifier when the antenna tuner is bypassed.

FREQUENCY GENERATOR

The frequency generator, shown in figure 14-28, is an important part of the AN/URC-32 transceiver. The band change and frequency change controls on the front panel of the frequency generator determine the frequency to which the unit is tuned.

The frequency generator (fig. 14-29) consists of a main chassis and five plug-in units. These units are:

1. R-f tuner;
2. Stabilized master oscillator;
3. Sidestep oscillator;
4. Frequency divider; and
5. Reference oscillator.

All five units are shown in figure 14-30 in greater detail.

R-F Tuner

The r-f tuner of the frequency generator (lower part of fig. 14-30) is an i-f to r-f translator during transmit condition, and an r-f to i-f translator during receive condition. During the transmit condition, the r-f tuner accepts the 300-kc single-sideband signal from the balanced modulators of the sideband generator (fig. 14-24) and translates it to any desired frequency (in 1-kc steps) in the range from 2.0 to 30.0 mc.

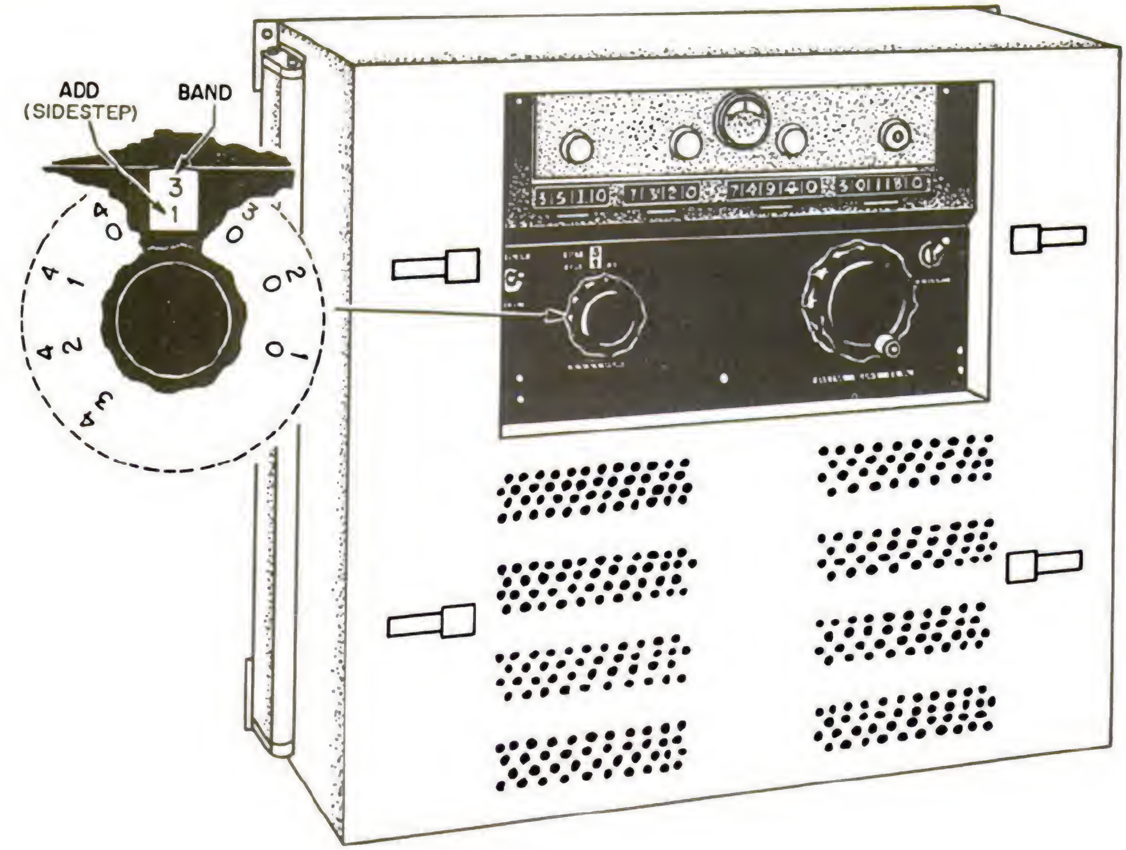

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Figure 14-28—AN/URC-32 frequency generator.

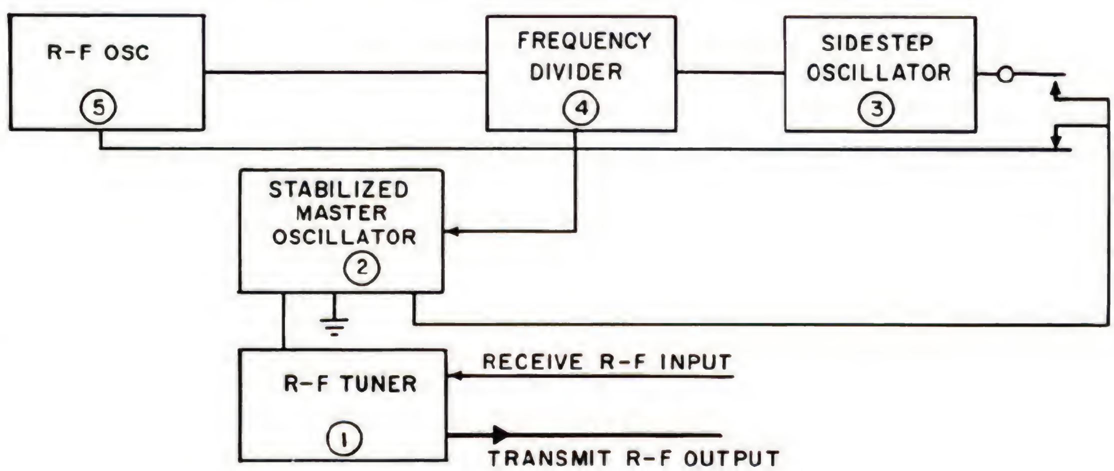

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Figure 14-29.—Frequency generator, simplified block diagram.

During receive condition, the r-f tuner accepts the selected received signal (as indicated on the band dial of fig. 14-28) and translates it to a 300-kc i-f signal. This signal is fed to the i-f/a-f amplifier of the sideband generator (or a-m/i-f amplifier, depending on the type of reception) for demodulation and amplification, as discussed earlier in this chapter.

The r-f tuner is tunable through its normal operating range (2.0 to 30.0 mc) in four bands. These bands are:

Band 1—1.7 to 3.7 mc;
Band 2—3.7 to 7.7 mc;
Band 3—7.7 to 15.7 mc;
Band 4—15.7 to 31.7 mc.

The r-f tuner can be tuned in 1-kc steps over the entire tuning range.

During transmit and receive conditions on band 1, the r-f tuner performs a single frequency conversion. The heterodyning process takes place in V1A (fig. 14-30) for transmit and in V1B for receive. On bands 2, 3, and 4, the r-f tuner performs a double frequency conversion in either V3A or V3B.

On receive operation, the r-f input signal from the transmit-receive relay (at the antenna input) is fed through the keying relay K2 to receiver r-f amplifier V8. (K2 permits passage of the received signal during receive condition and K1 applies an additional bias to cut off the stages of the receiver during transmit.) On bands 2, 3, and 4, the output of V8 is fed to receive h-f mixer V3B where it is converted to a 1.7- to 3.7-mc variable i-f signal.

On band 1, the output of V8 is in the 1.7- to 3.7-mc range and is fed directly to receive i-f amplifier V7. The 1.7- to 3.7-mc variable i-f signal (during receive operation) is amplified by receive i-f amplifier V7 and fed to receive i-f mixer V1B, where it is converted to a 300-kc fixed i-f signal. The V1B output is fed to the i-f/a-f amplifier of the sideband generator (fig. 14-24). An automatic gain control (AGC) voltage from the sideband generator controls the gain of the receiver amplifiers V7 and V8 (fig. 14-30).

On transmit operation, the 300-kc fixed i-f signal from the balanced modulators of the sideband generator is converted to a 1.7- to 3.7-mc variable i-f signal in transmit i-f mixer V1A by mixing with a 2 to 4 mc signal from the stabilized master oscillator. The variable i-f signal is amplified by transmit i-f amplifier V2. The gain of V2 is controlled by a TGC (transmit gain control) voltage from the TGC unit of the sideband generator. On band 1, the output of V2 (fig. 14-30) is fed through the band-change switch to the transmit r-f amplifier V4.

During transmission on bands 2, 3, and 4, the output of V2 is fed through the band-change switch to the transmit h-f mixer V3A, where it is converted to an r-f signal in the range of 3.7 to 31.7 mc, depending on the band selected. The transmit h-f mixer V3A is followed by three stages of r-f amplification on band 2, and by two stages of amplification on bands 1, 3, and 4. The necessity for greater amplification on band 2 is caused by losses in special tuned circuits used during transmission on this band. The output from V6 is fed to the power amplifier unit.

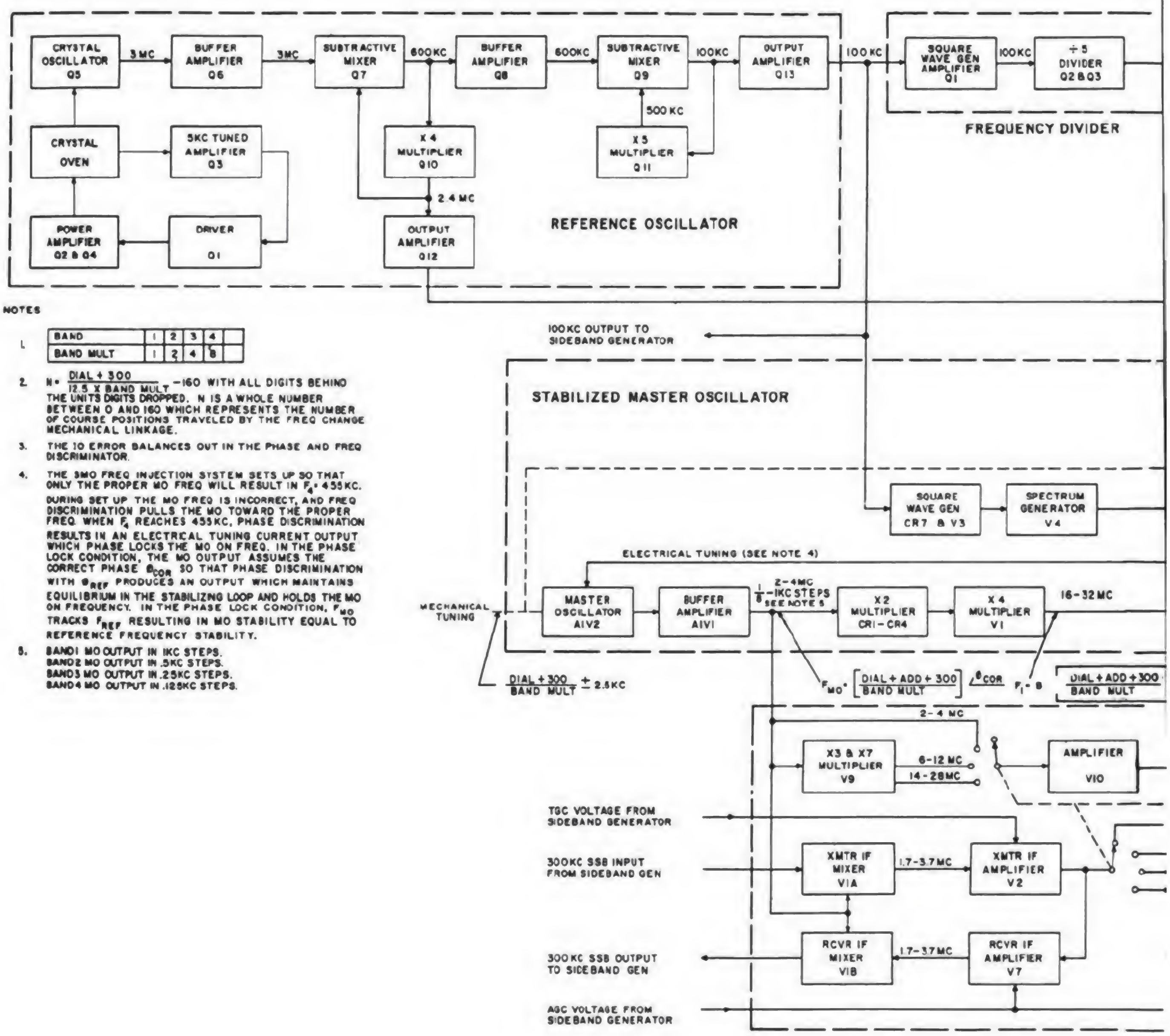
Stabilized Master Oscillator

In conventional a-m transmitters, the final output is obtained by multiplying the basic oscillator frequency in one or more stages. Special care must be taken to ensure that the multiplier stages operate at an exact harmonic frequency during tuning, and that the stages remain on frequency throughout the transmission.

In single-sideband transmitters, the final output generally is obtained by heterodyning in mixer stages. The sum frequency can be many times the original frequency and contain the same modulation components. To yield the desired output frequency, the injection frequency must be exact, and it may be controlled automatically. This process is used in the transmitter section of the AN/URC-32.

The stabilized master oscillator (center section, figure 14-30) consists of a master oscillator and a stabilizing loop that provides error correction for the master oscillator. The master oscillator is an inductance-tuned oscillator that can be adjusted mechanically in 0.5-kc increments through the frequency range of 2 to 4 mc. It can be tuned to any 1 of 2000 1-kc r-f tuner channels in band 1 and any 1 of 4000 1-kc r-f tuner channels in band 2.

Bands 3 and 4 of the r-f tuner, containing 8000 and 16,000 1-kc channels, respectively, require the master oscillator to produce a greater number of injection frequencies than are possible with the mechanical positioning device. Generation of the additional increments is accomplished by positioning the master oscillator mechanically to the nearest lower 0.5-kc increment and then operating the stabilizing loop automatically to position the master oscillator



NOTES

1.

BAND	1	2	3	4	
BAND MULT	1	2	4	8	

2. $N = \frac{\text{DIAL} + 300}{12.5 \times \text{BAND MULT}} - 160$ WITH ALL DIGITS BEHIND THE UNITS DIGITS DROPPED. N IS A WHOLE NUMBER BETWEEN 0 AND 160 WHICH REPRESENTS THE NUMBER OF COURSE POSITIONS TRAVELED BY THE FREQ CHANGE MECHANICAL LINKAGE.

3. THE 10 ERROR BALANCES OUT IN THE PHASE AND FREQ DISCRIMINATOR.

4. THE SMO FREQ INJECTION SYSTEM SETS UP SO THAT ONLY THE PROPER MO FREQ WILL RESULT IN $F_4 = 455$KC. DURING SET UP THE MO FREQ IS INCORRECT, AND FREQ DISCRIMINATION PULLS THE MO TOWARD THE PROPER FREQ. WHEN F_4 REACHES 455KC, PHASE DISCRIMINATION RESULTS IN AN ELECTRICAL TUNING CURRENT OUTPUT WHICH PHASE LOCKS THE MO ON FREQ. IN THE PHASE LOCK CONDITION, THE MO OUTPUT ASSUMES THE CORRECT PHASE θ_{COR} SO THAT PHASE DISCRIMINATION WITH θ_{REF} PRODUCES AN OUTPUT WHICH MAINTAINS EQUILIBRIUM IN THE STABILIZING LOOP AND HOLDS THE MO ON FREQUENCY. IN THE PHASE LOCK CONDITION, F_{MO} TRACKS F_{REF} RESULTING IN MO STABILITY EQUAL TO REFERENCE FREQUENCY STABILITY.

5. BAND1 MO OUTPUT IN 1KC STEPS.
BAND2 MO OUTPUT IN .5KC STEPS.
BAND3 MO OUTPUT IN .25KC STEPS.
BAND4 MO OUTPUT IN .125KC STEPS.

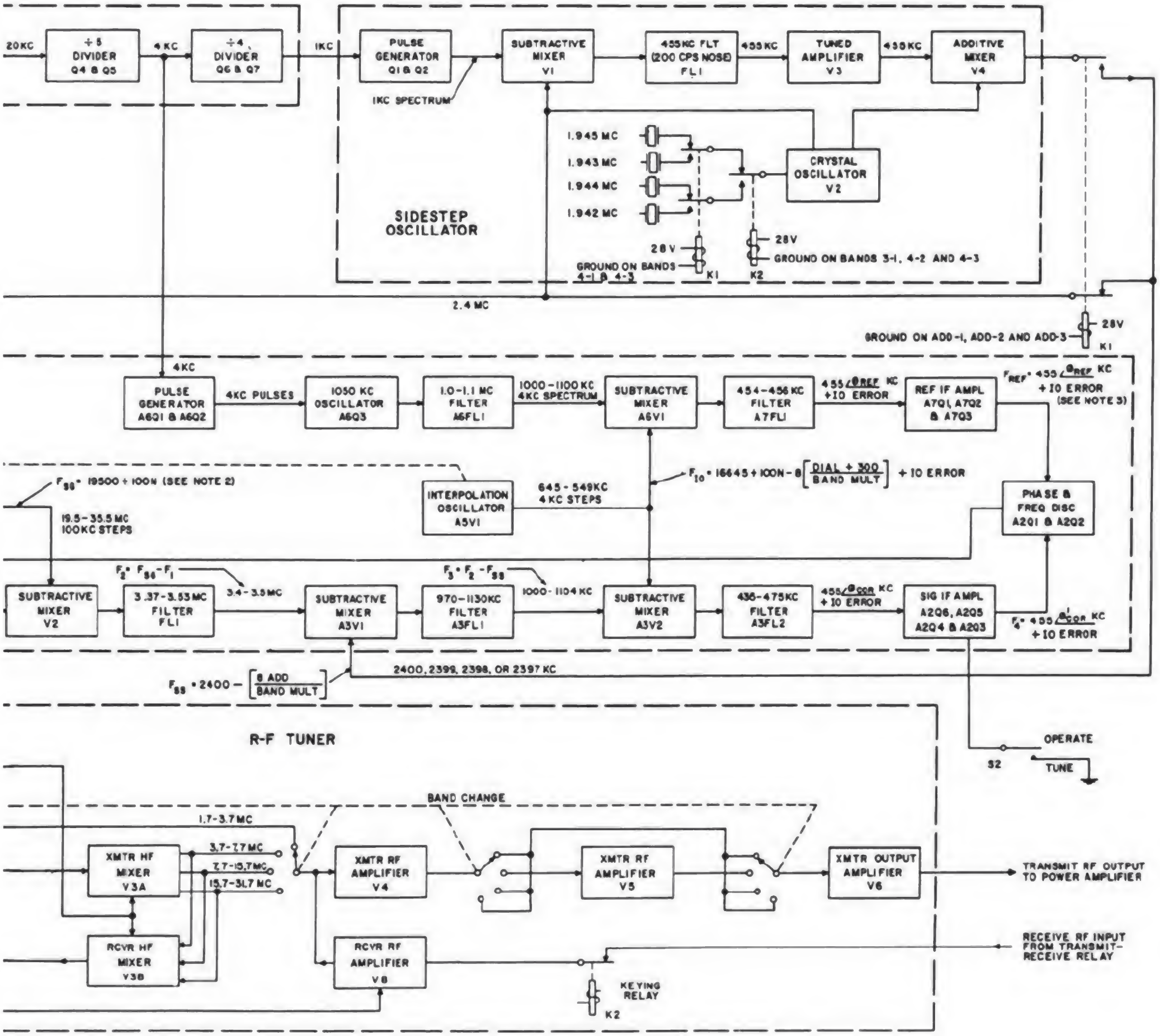


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Figure 14-30: —Frequency generator, block diagram.

electronically to the additional required increments.

Electronic tuning of the master oscillator is accomplished by varying the d-c component of current in a saturable reactor located in the tuning circuit of the oscillator. This process is described later. The master oscillator output frequency can be computed by the formula:

$$FMO = \frac{DIAL + ADD + 300}{BAND\ MULT}$$

Where FMO	=	the master oscillator frequency in kilocycles;
DIAL	=	the frequency generator dial frequency
ADD	=	the ADD KC indication on the band change switch (fig. 14-28);
300	=	the 300-kc fixed i-f subtracted in the r-f tuner i-f mixer;
BAND MULT	=	multiplication of the master oscillator frequency in the r-f tuner
Band 1	=	1; BAND 2 = 2; BAND 3 = 4; BAND 4 = 8.

The master oscillator stabilizing loop tunes the master oscillator electronically to the desired frequency and phase-locks it to the reference oscillator, thereby maintaining a master oscillator frequency accuracy and stability equal to that of the reference oscillator. This action is accomplished by comparing the master oscillator signal with the reference oscillator signal in a phase and frequency discriminator.

The stabilizing loop operates as follows:

The 2- to 4-mc output of the master oscillator is multiplied by 8 and applied to mixer V2, where it is beat with a selected 100-kc signal from the spectrum generator.

The triggering signal for the 100-kc spectrum generator is obtained from the reference oscillator. The output of mixer V2 is filtered in FL1 and applied to mixer A3V1, where it is beat with a signal from the sidestep oscillator or the reference oscillator.

The sidestep oscillator injection is used to obtain, electronically, the frequency increments that cannot be obtained by mechanically tuning the master oscillator. The output of mixer A3V1 is filtered to obtain a difference frequency between 970 and 1130 kc and applied to mixer A3V2, where it is beat with a signal from the interpolation oscillator. The interpolation oscillator A5V1, which is tuned by a mechanically operated tuning shaft, supplies an injection signal, which produces a mixer difference frequency F4. This frequency is 455 kc plus the master oscillator error and the interpolation oscillator error.

The mixer A3V2 output frequency (F4) is filtered, amplified, and applied to the phase and frequency discriminator. Here F4 is compared with a reference frequency (F_{REF}).

The reference frequency (F_{REF}) is generated by converting a 4-kc signal from the frequency divider to a 4-kc spectrum in the 1000- to 1100-kc frequency range and mixing it in A6V1 with the interpolation oscillator output. The reference frequency (F_{REF}) is equal to 455 kc plus the interpolation oscillator error. The interpolation error present in both F_{REF} and F4 is balanced out in the phase and frequency discriminator.

When F4 (which contains the oscillator error) is exactly 455 kc, phase discrimination of F_{REF} and F4 results in a tuning current output from the discriminator (f-m detector), which phase-locks the master oscillator on frequency. In the phase-locked condition, the master oscillator output frequency assumes the correct phase (Φ_{COR}) and, in comparison with the reference phase (Φ_{REF}), produces an output which maintains equilibrium in the stabilizing loop and holds the master oscillator on frequency. Thus, in the phase-locked condition, the master oscillator frequency (F_{MO}) tracks the reference frequency (F_{REF}), resulting in a master oscillator stability equal to the reference frequency stability.

Sidestep Oscillator

The sidestep oscillator (shown also in fig. 14-30) provides the injection frequency for the subtractive mixer A3V1 of the stabilized master oscillator. The term "sidestep" refers to a change from a given frequency by a definite number of kilocycles. The injection frequency is sidestepped by 1, 2, or 3 kc, as required, to obtain the electronic tuning necessary to supplement the mechanical tuning of the master oscillator in the SMO. The sidesteps 1, 2, and 3, are referred to as ADD 1, ADD 2, and ADD 3,

respectively, and indicate the number of kilocycles the sidestep oscillator output is displaced from 2400 kc.

The output of the pulse generator (Q1, Q2), the 2.4-mc injection signal, and the crystal oscillator V2 output are mixed in the subtractive mixer V1 to provide a 455-kc output. This signal is mixed with the crystal oscillator output in additive mixer V4 to produce the sidestep oscillator output. The output can be changed in steps of 1 kc by selection of the V2 crystal oscillator frequency, while maintaining a stability on all output frequencies equal to that of the reference oscillator input.

Frequency Divider

The frequency divider (top center, fig. 14-30) supplies a 4-kc signal to the stabilized master oscillator and a 1-kc signal to the sidestep oscillator.

The frequency divider consists of square wave generator-amplifier Q1 and three multivibrator-type frequency dividers. The 100-kc signal from the reference oscillator is amplified in Q1, and divided to 20 kc by one multi-vibrator (Q2 and Q3). The 20-kc signal is divided to 4 kc by another multi-vibrator (Q4 and Q5), and the 4-kc signal is divided to 1 kc by a third multivibrator (Q6 and Q7). Because the 4-kc and 1-kc input signals are derived from the 100-kc input signal, their stability is equal to that of the reference oscillator.

Reference Oscillator

The reference oscillator (top left, fig. 14-30) provides the basic reference frequencies of 100 kc and 2.4 mc for the entire equipment. Because the frequency accuracy of the equipment depends on the stability of the 3-mc crystal oscillator, the crystal is enclosed in a temperature-controlled oven.

The 3-mc output of the crystal oscillator is fed through buffer amplifier Q6 to a regenerative divider circuit. This circuit consists of subtractive mixer Q7 and times 4 multiplier stage Q10.

The 2.4-mc output of the Q10 multiplier stage is fed through output amplifier Q12 to the sidestep oscillator.

The 600-kc output of the regenerative circuit is fed through buffer amplifier Q8 to another regenerative divider, which consists of subtractive mixer Q9 and times 5 multiplier stage Q11. Buffer Q8 isolates the two regenerative circuits. The 100-kc output of the divider circuit is amplified in Q13 and fed to the frequency divider, the stabilized master oscillator, and to the sideband generator. The 100-kc output of the reference oscillator represents the frequency standard for the equipment, and has a long-term stability of one part per million.

POWER AMPLIFIER

The power amplifier (fig. 14-31) is a two-stage r-f power amplifier, which amplifies the 0.15-watt PEP signal from the frequency generator to a nominal output power of 500 watts PEP. As shown in figure 14-32, it contains a driver stage (V1-V2), a power amplifier stage (V3-V4), a transmit gain control (TGC) rectifier, a bias and filament supply, and the necessary control and interlock circuits.

The driver and power amplifier plate circuits are tuned manually through the frequency range of 1.7 to 31.7 mc in four bands. The power amplifier plate circuit uses a tuned pi network to obtain an unbalanced 50-ohm output impedance over the complete range of frequencies.

Driver Stage

The output r-f signal from the r-f tuner is fed through coaxial cable to r-f input jack J1 (fig. 14-33). Resistor R1 terminates the line in its characteristic impedance.

Driver tubes V1 and V2 are connected in parallel to increase the current-carrying capabilities of the stage and to ensure conservative operation of the tubes. Parasitic suppressors Z1 and Z2 reduce the generation of undesired frequencies.

The shunt-fed plate output tuned circuit of V1 and V2 comprises variable inductor L4 and one of the capacitors (C16, C17, or C18) in shunt with the input capacitance between the grid and ground of the power amplifier stage. The driver plate tank is tuned to the desired operating frequency by the driver tune control on the PA front panel (fig. 14-31), which varies the inductance of L4 (fig. 14-33).

Driver-PA band selector switch S4 (section S4A) selects the V1 and V2 driver plate tuning capacitance for operation on any of the four bands. The switch is shown in the band 1 position. On bands 2, 3, and 4, S4A connects one of the resistors (R28, R27, or R26) in parallel with the tuned circuit. This action reduces the

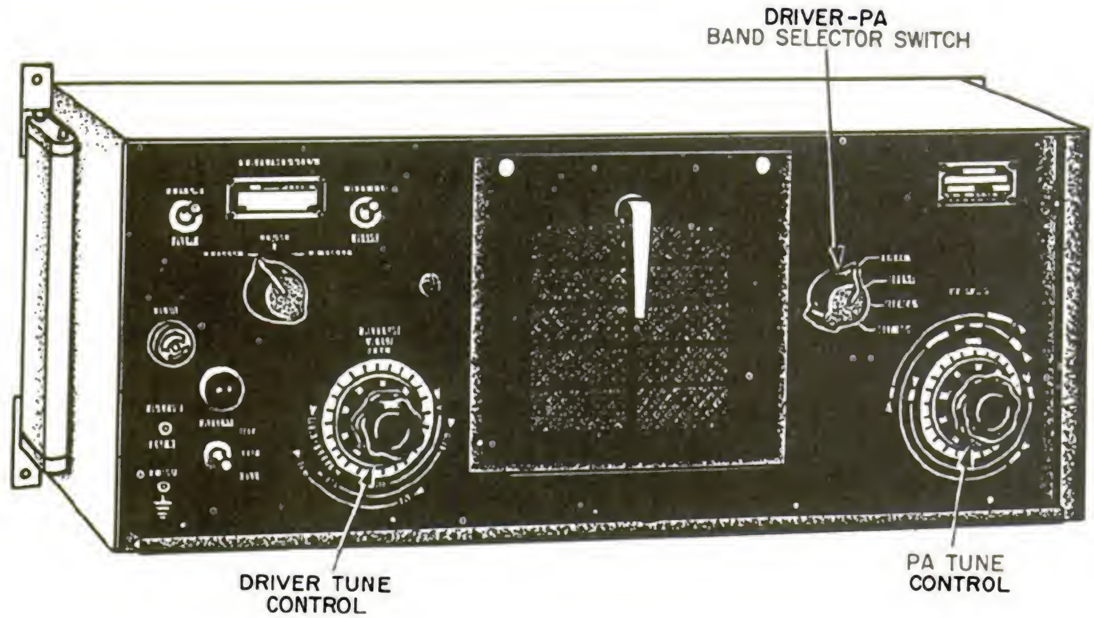

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Figure 14-31.--Power amplifier.

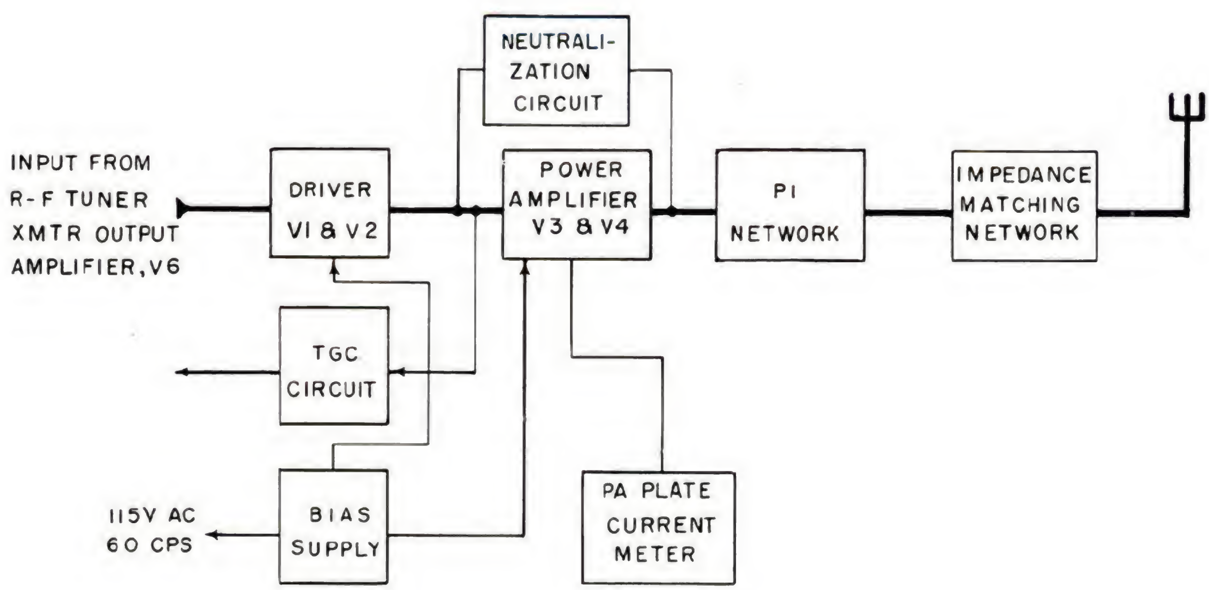

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Figure 14-32.—Power amplifier, block diagram.

Q of the circuit from that obtained on band 1 so that the V3 and V4 power amplifier grid driving voltage remains approximately equal on each of the four bands.

Power Amplifier Stage

The power amplifier stage (V3 and V4) is parallel connected and uses two tetrodes. Parasitic suppressors R38 (in the grid input path) and Z3 and Z4 (in the plate circuits) suppress undesired oscillations.

The driver (V1 and V2) output from the C9-L4 junction is amplified in V3 and V4. On bands 1 and 2, L8 and L9 in series constitute the PA plate load inductance. For operation on bands 3 and 4, S4D closes (opposite to the position shown) to short L9.

Capacitor C20 couples the 500-watt PEP output signal from the power amplifier to a pi network (low pass filter) consisting of C33, PA tune control L10, C29, and any of the capacitors C21 through C28, as determined by the position of S4B. The C33 and C29 capacitances are used in the network on all bands. On band 1, driver-PA band selector switch S4B connects C21 to C28 inclusive in parallel with C33. On band 2, S4B removes C21 and C25 to C28 inclusive from the circuit. On band 3, S4B removes C23 and C24, in addition to those previously removed. On band 4, only C33 and C29 remain in the pi network. PA tune control L10 tunes the pi network to the desired operating frequency within the selected band. With proper adjustment, the pi network presents a 50-ohm output impedance over all four bands.

Loading the transmitter is accomplished for each of the four bands by switching taps on L11, and by the selection of one of the capacitors C30, C31, or C32. Both the L and C selections are made by S4C. The loading network permits the transmitter output to be tuned over the entire 1.7- to 31.7-mc range with nearly constant output. Output power is delivered via r-f output jack J2 to an antenna network (if used) or to the antenna.

NEUTRALIZATION.—A bridge neutralization circuit is included in the power amplifier stage (V3 and V4) to balance out the feedback from plate to grid owing to interelectrode capacitance of the tubes. Simplified diagrams of the neutralizing circuit are shown in figure 14-34.

The neutralizing feedback voltage is applied from the plates of V3 and V4 (fig. 14-34A) to the grids of these tubes through C10, C8 and C12. These capacitors are lumped together as Cn in figure 14-34B. The grid-plate interelectrode capacitance is represented as Cgp, and Cgf represents the sum of the input capacitances to V3 and V4, which consists of the grid-cathode interelectrode capacitance and all stray capacitance. The combined capacitance, along with the driver-tank inductance L4, form the bridge circuit in figure 14-34B.

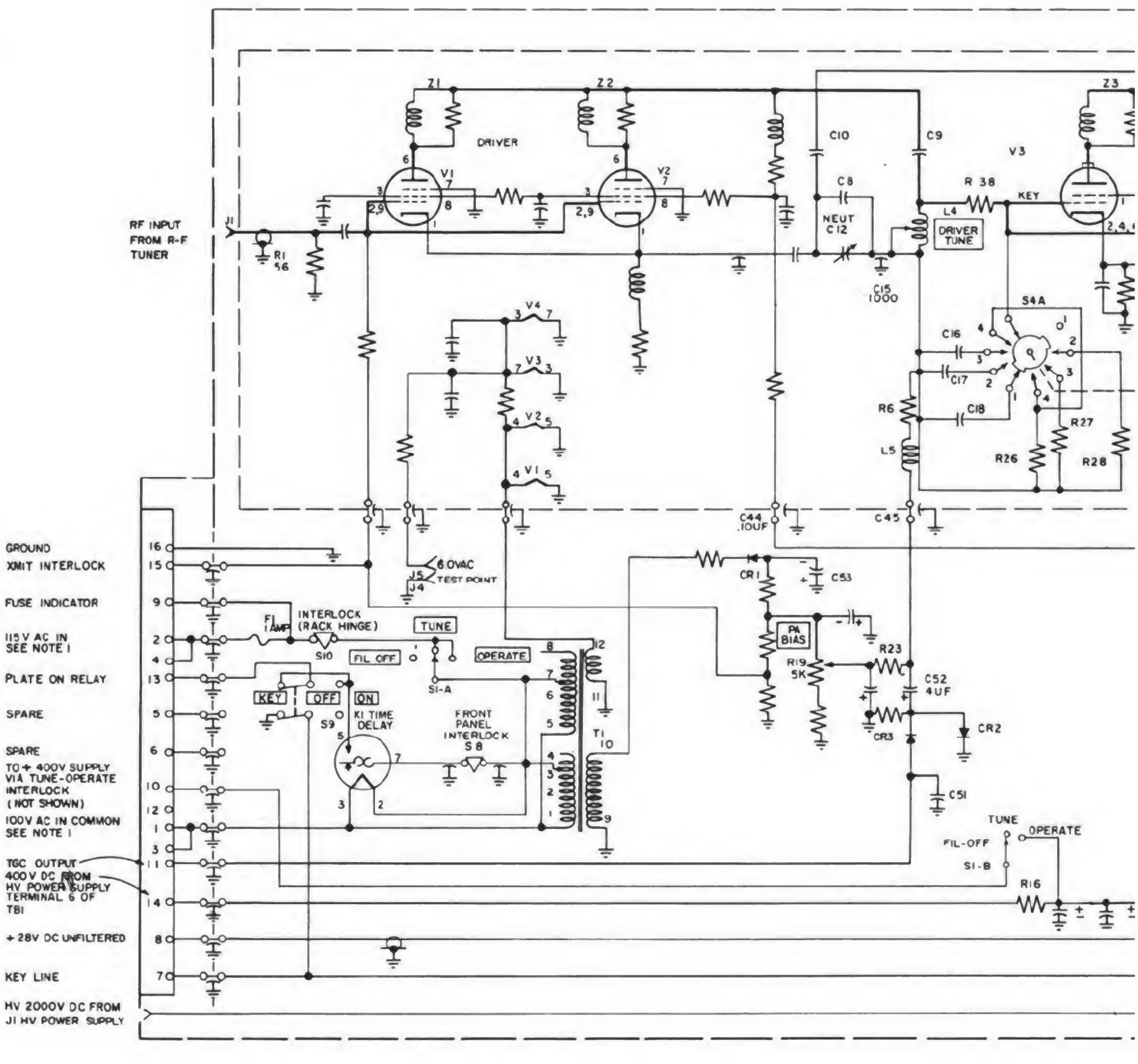
The grid-plate capacitance Cn can be adjusted within limits for different amount of feedback voltage. The Cn capacity is adjusted properly when Ecn = Ecgp. Because L4 is connected between diagonally opposite corners of the bridge, it follows that the bridge is balanced when $\frac{Ecn}{Ec15} = \frac{Ecgp.}{Ecgf}$ When this occurs, the r-f feedback potential to ground from both ends of L4 is equal and in phase so that no feedback r-f voltage via Cn or Cgp is developed across L4. Only the output voltage across the L4 driver tank is applied to the V3-V4 grids.

TRANSMIT GAIN CONTROL CIRCUIT.—The transmit gain control circuit (fig. 14-35) automatically adjusts the gain of the transmitter i-f amplifier in the r-f tuner and of the TGC amplifier in the sideband generator. The TGC output (fig. 14-35) is a negative voltage applied to the grids of these stages. This action ensures that the driving signal to the power amplifier V3 and V4 (fig. 14-33) will operate the power amplifier tubes at maximum capability but that it will not overdrive the tubes.

The TGC output voltage is obtained by rectifying a small portion of the driver (V1-V2) output signal which exists from the bottom of the driver-plate-tank to ground (across C15).

The amplitude of the driver-plate-tank input controls the amplitude of the TGC output. With no audio input, the driver-plate-tank signal is zero and the TGC bias across C51 comes from the PA bias supply.

With an audio input, the amplitude of the driver-plate-tank voltage increases, and C51 charges to a higher voltage. The C51 output is negative to ground and comprises the TGC signal.


RF INPUT FROM R-F TUNER
GROUND
XMIT INTERLOCK
FUSE INDICATOR
115V AC IN SEE NOTE 1
PLATE ON RELAY
SPARE
SPARE
TO + 400V SUPPLY VIA TUNE-OPERATE INTERLOCK (NOT SHOWN)
100V AC IN COMMON SEE NOTE 1
TGC OUTPUT
400V DC FROM HV POWER SUPPLY TERMINAL 6 OF TB1
+ 28V DC UNFILTERED
KEY LINE
HV 2000V DC FROM J1 HV POWER SUPPLY
DRIVER
DRIVER TUNE
NEUT C12
INTERLOCK (RACK HINGE)
TUNE
FIL OFF
OPERATE
KEY
OFF
ON
K1 TIME DELAY
FRONT PANEL INTERLOCK S8
6.0VAC TEST POINT
PA BIAS
R19 5K
C52 4UF
C44 .10UF
C15 1000
FIL-OFF
S1-B
S4A

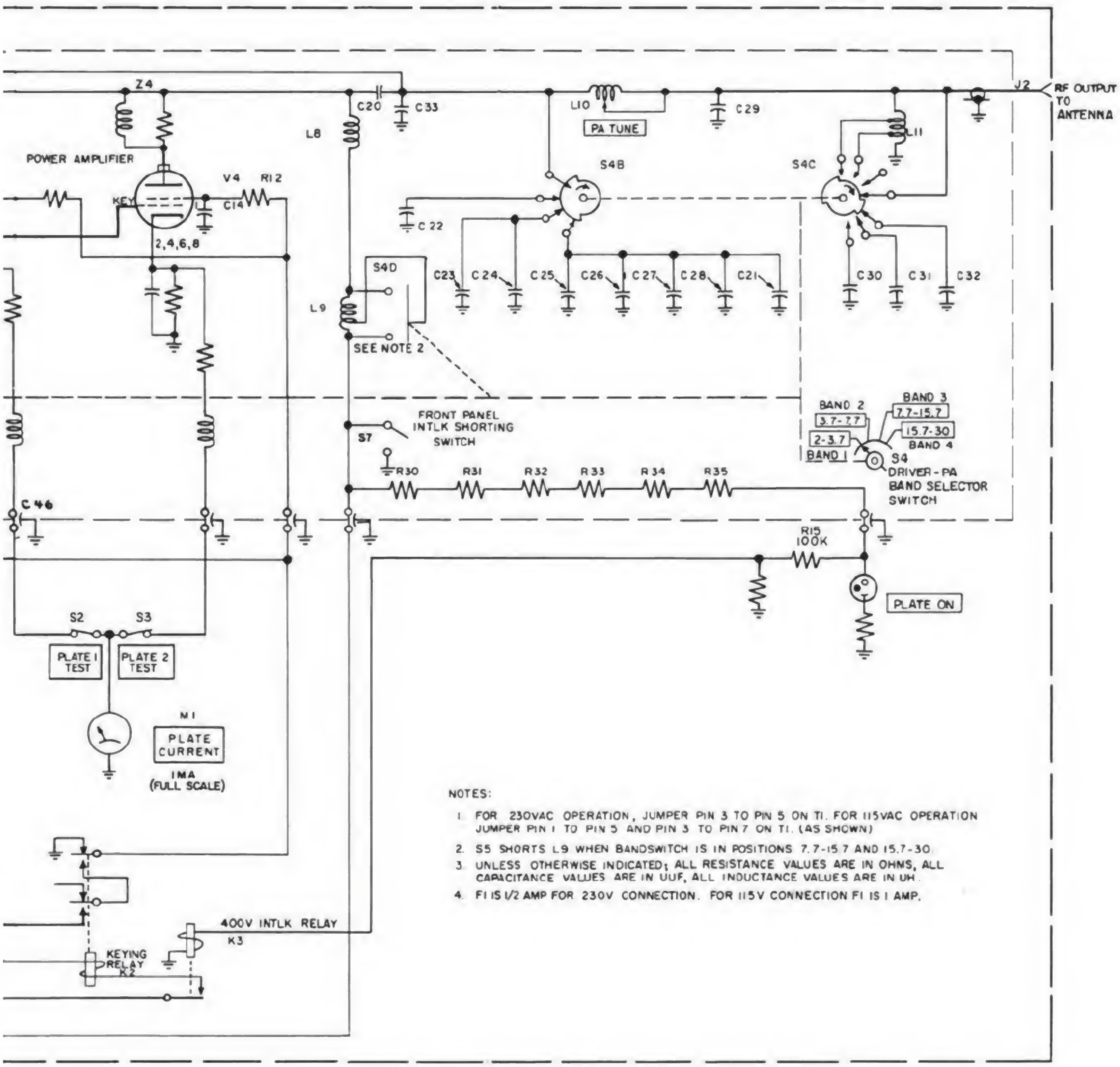


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Figure 14-33.—Power amplifier, schematic diagram.

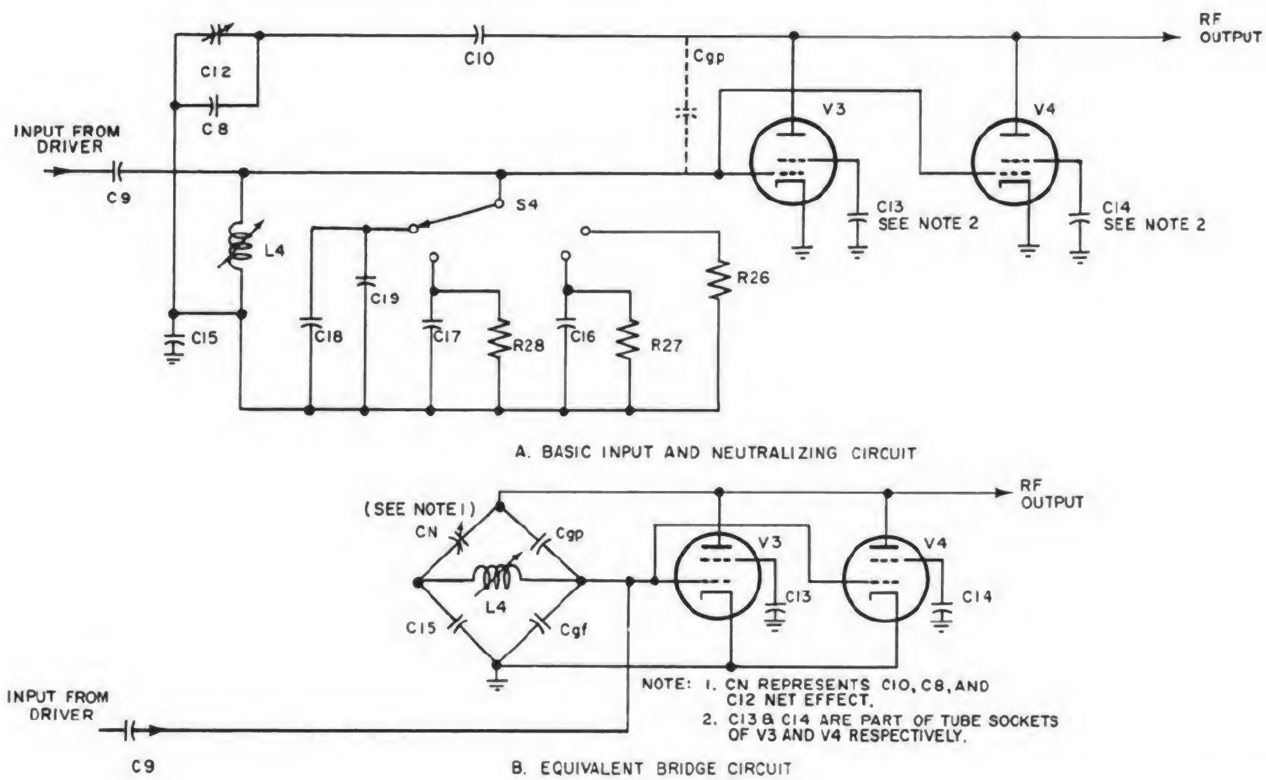

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Figure 14-34.—Power amplifier, neutralizing circuit.

POWER SUPPLIES

Plate voltage for the power amplifier tubes V3 and V4 (fig. 14-33) is obtained from the +2000-volt high-voltage supply shown in figure 14-36. The high-voltage power supply utilizes eight series-connected silicon rectifiers in each leg of a bridge circuit. Silicon rectifiers operate efficiently at much higher temperatures than selenium or germanium rectifiers. In addition, silicon rectifiers have less reverse (leakage) current, which results in less power loss and less heat radiation in the power supply unit.

The input voltage is applied to transformer T1 through relay K1. The output of the transformer is coupled to the two rectifier bridges, which are connected in series to provide +2000-volt and +400-volt d-c output. Switch S1 is a case interlock that operates switch S2 to the open position (as shown) when the power supply cabinet is closed. The 400-volt d-c supply consists of rectifiers CR1 through CR12, connected in a conventional full-wave bridge rectifier circuit. The output is fused by F2 and filtered by inductor L2 and resistor R1. The 2000-volt d-c supply consists of CR13 through CR44. The output is filtered by L1, C1, and C2. Fuse F3 protects the circuit, and resistors R2, R3, and R4 are bleeders.

A low-voltage power supply (fig. 14-37) provides several outputs of relatively low voltage. The input voltage is applied to the primary of transformer T1 through switch S1. The secondary of the transformer supplies all the full-wave bridge rectifier and choke input filter. The +130-volt supply is connected to the center tap of the +250-volt supply and contains an LC filter. Indicator light DS1 is tied across the 12.6-volt a-c supply. The unfiltered +28-volt supply is taken from directly across the full-wave rectifier diodes

CR6 and CR7. The partly filtered +28-volt supply is taken from across a one-section LC network. The filtered, regulated 28-volt d-c supply is isolated from the other 28-volt d-c supplies by diode CR8. This ɜnts C4 and C6 from discharging into the low impedance of the other supplies. After passing through an RC filter, the output voltage is clamped by Zener diode CR9, which conducts when the voltage across it rises above 27 volts d-c. The -90-volt supply uses a half-wave rectifier with an RC filter.

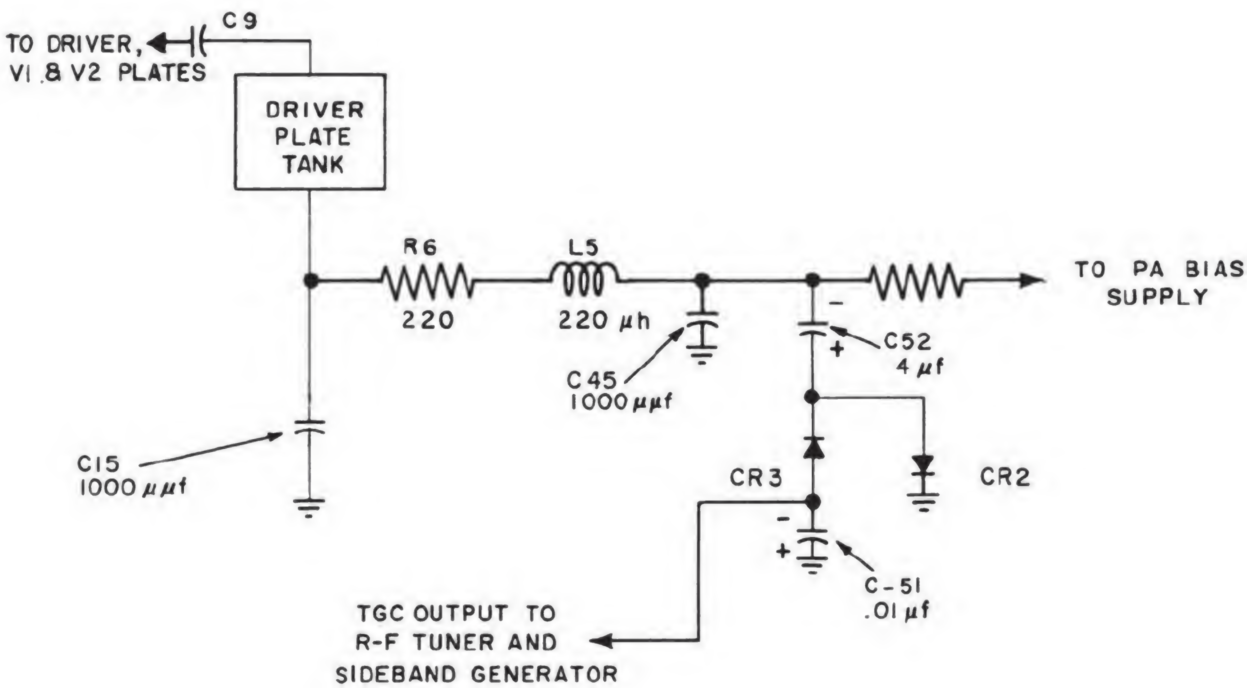

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Figure 14-35.—Transmit gain control (TGC) circuit.

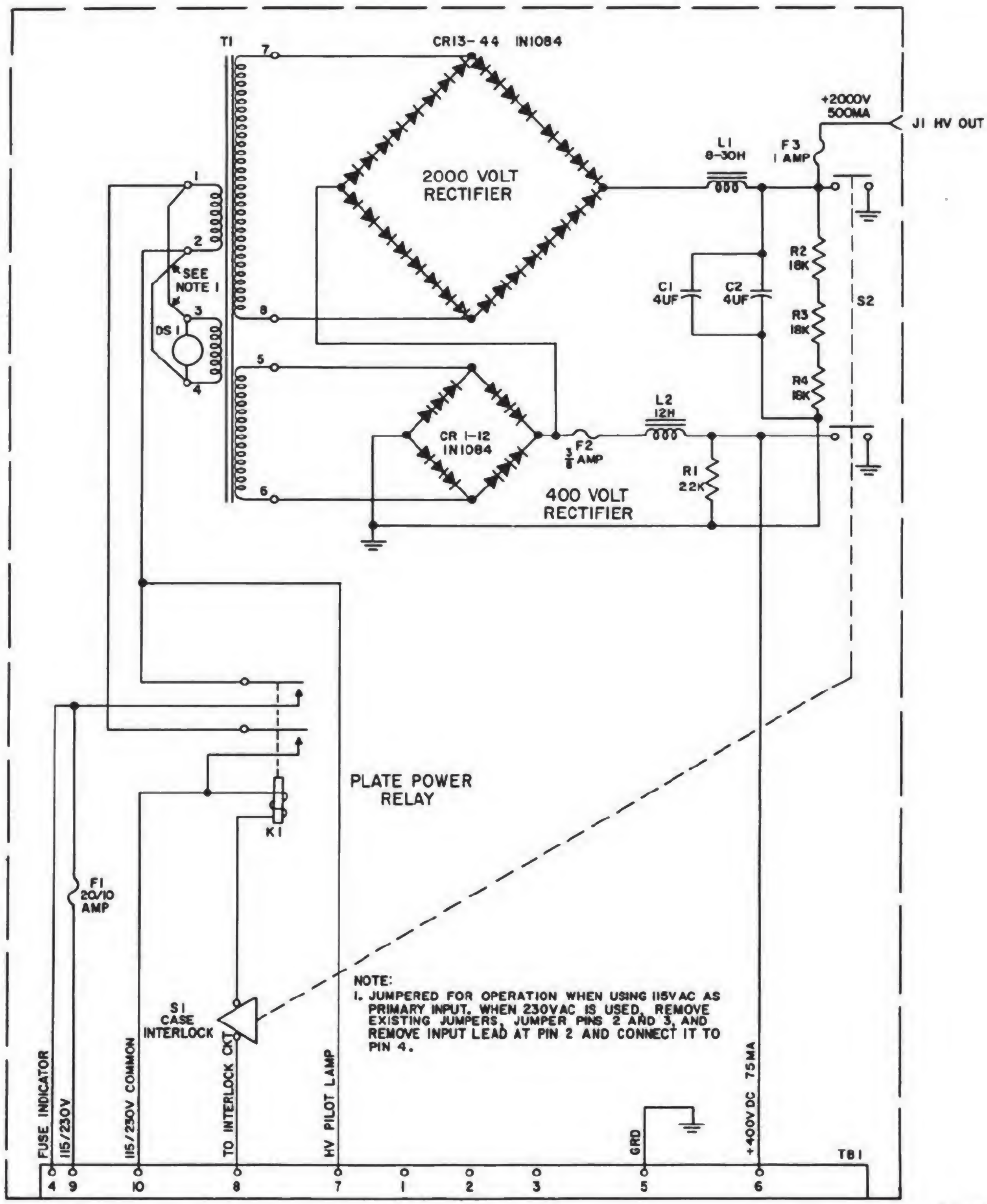

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Figure 14-36.—High-voltage power supply, schematic diagram.

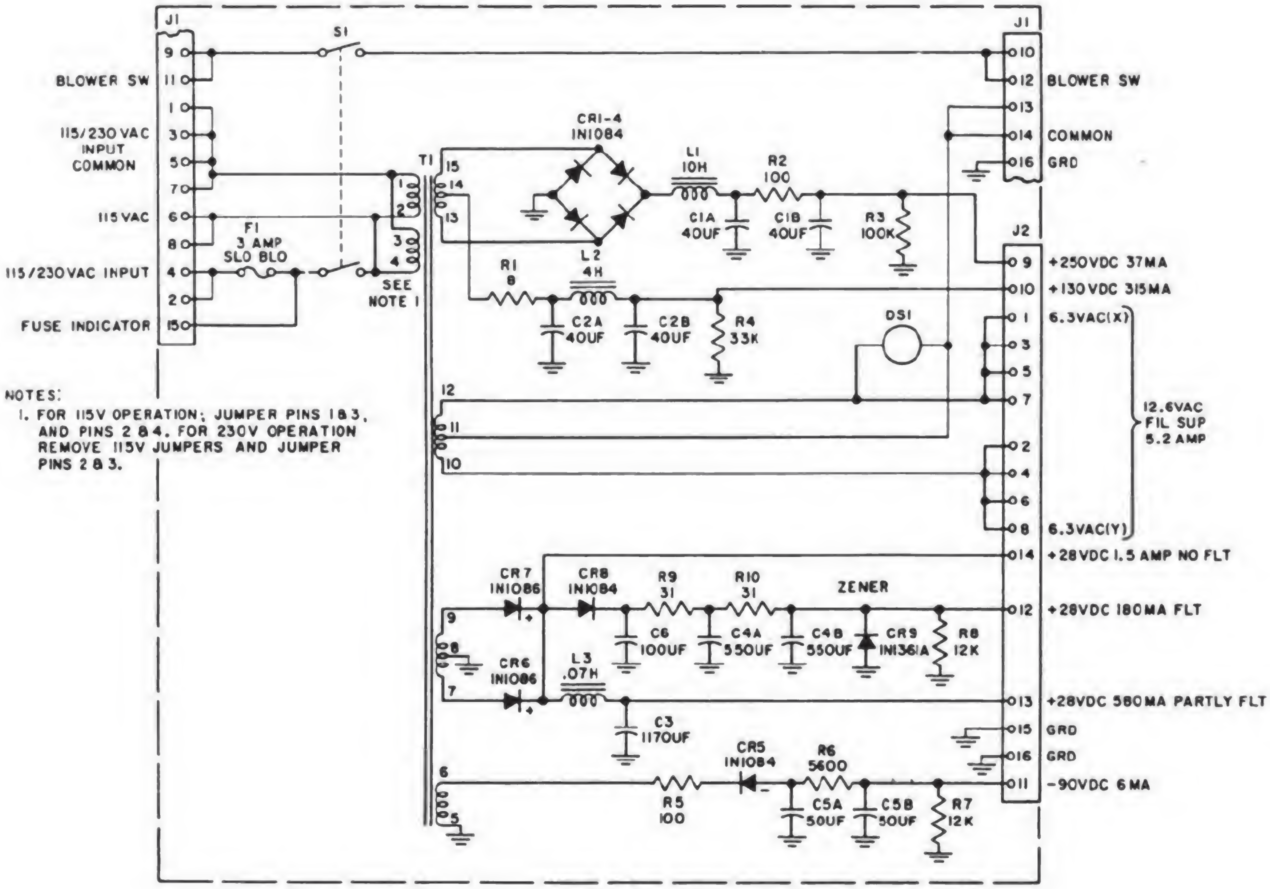

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Figure 14-37.—Low-voltage power supply, schematic diagram.

CHAPTER 15

PRINCIPLES OF COMMUNICATIONS MULTIPLEXING

The number of communications networks in operation per unit of time throughout any given area is constantly increasing. In the past, each network has been required to operate on a different radio frequency. As a result, all areas of the r-f section have become highly congested.

To a great extent, the maximum permissible number of intelligible transmissions taking place in the radio spectrum per unit of time is being increased through the use of multiplexing. Multiplexing involves the transmission of several intelligible signals on the same frequency during the same period of time normally required for the transmission of a single signal. Either of two methods of multiplexing may be used. These are time-division and frequency-division multiplexing.

TIME-DIVISION MULTIPLEXING

With a-m voice and tone communications, it is desired to transmit and receive the full 360° of each sine wave (fig. 15-1A). However, an audio signal may be transmitted and received satisfactorily by periodically sampling the signal. The result of the sampling process yields a received signal such as that shown in figure 15-1B. Slightly more than two samples per cycle of audio will give reasonably satisfactory results. In practical systems, 2.4 samples per cycle are usually taken. This concept of sampling forms the basis for time-division multiplex operation.

Figure 15-2A, illustrates in a highly simplified form the basic principle of time-division multiplexing. Assume that a 3,000-cycle tone is applied to each of the six channels in the transmitter. Assume also that the rotating switch turns fast enough to sample, in turn, each of the six channels 2.4 times during each cycle of the 3,000-cycle tone. The speed of rotation of the switch must then be 2.4 x 3,000, or 7,200 rotations per second.

If the transmitter and receiver switches are synchronized, the signals will be fed in the proper sequence to the receiver channels. The transmitted samples from transmitter channel 1 will be fed to receiver channel 1. Thus, in the time-division method of multiplexing, many channels of audio are combined (with time spacing between components of the separate channels) to form a single output (multiplexed) chain. The chain is transmitted, via wire or radio facilities to distant demultiplexing receivers, each of which functions to select only the information pertaining to its particular channel.

A mechanical system is shown here for the sake of simplicity. In actual operation, any mechanical switching arrangement would not be able to provide the high speed of switching that is required for a multiplexing system. For this reason, electronic switching is used.

A sine wave sampled four times for each channel is illustrated in figure 15-2B. In an actual transmission, segments from the waveforms in all of the channels will be interspaced with these four segments on a time-sharing basis. In other words, only one segment can be transmitted at a time; and the segments are taken in sequence from the waveforms existing in the six channels.

More than six channels (perhaps 24 or more) may be used. However, as the the number of channels is increased, the width of each segment must be proportionately reduced. The great disadvantage in reducing the width of the pulse is that the bandwidth necessary for transmission is greatly increased. Decreasing the pulse width will decrease the minimum required rise time and increase the required bandwidth because of the increase in the number of harmonics contained in the sharper leading edge of the pulse.

The bandwidth is also affected by the shape of the sampling pulse and the method of varying the pulse to carry the modulation. The methods used include pulse amplitude modulation, pulse

width modulation, and pulse position modulation. Pulse amplitude modulation is the type illustrated in figure 15-2. These methods are treated in more detail later.

In time-division multiplexing, to use time in the most efficient manner, the bandwidth necessary to transmit n channels would be only slightly wider than n times that necessary for one channel. However, the minimum bandwidth is not generally utilized.

TIME-DIVISION MULTIPLEX SYSTEMS

Either the amplitude or the frequency of the transmitted signals (samples) from the respective channels may be varied to effect modulation. Three practical methods of pulse modulation are used. These are pulse amplitude, pulse width (pulse duration), and pulse position modulation. In either case, a modulating pulse is made to vary at a rate dependent upon the frequency of the audio.

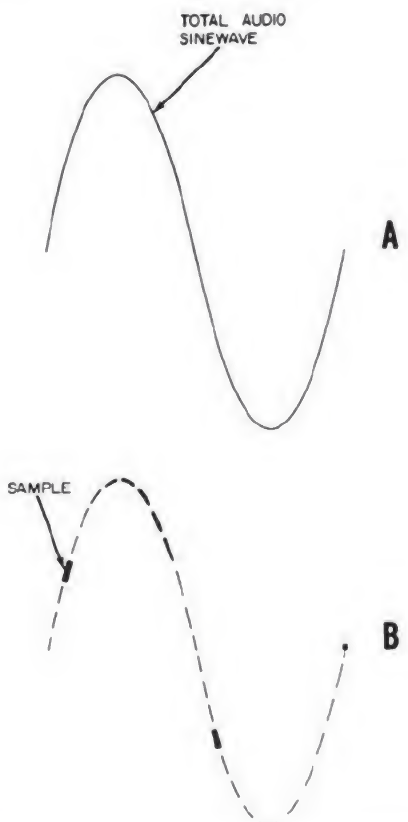

Figure 15-1.—Components of a sampled sine wave.

The sampling process allows modulating pulses (2.4 or more sampled at a fixed rate) to be introduced to the r-f transmitter carrier, or to the wire cable connecting the transmitting and receiving equipments. At least 2.4 of these samples must be transmitted for each cycle of the audio in order to produce an intelligible signal at the reproducer.

If the rate of sampling throughout the multiplex system is adjusted to 9.3 kc, then the maximum allowable audio frequency $= \frac{9300}{2.4} = 3875$ cps. This frequency represents the highest audio frequency that may be used. In practice, it is desirable to obtain a higher fidelity than can be realized with the minimum number of samples per second. For this reason, filters would be employed in this system to eliminate frequencies above about 3000 cps.

Sampling the audio signal of several channels through the use of electronic switching can be accomplished in several ways. A block diagram analysis of one method used in time-division multiplex is shown in figure 15-3. In this system, it is first necessary to develop a voltage that varies linearly with time. The sawtooth (time base) generator is of the boot-strap type, which uses a linearity stage to improve both voltage output and voltage linearity. Its output varies sufficiently linearly with respect to time to establish the basis for time-division multiplex.

The sawtooth generator output voltage (through the rise time) is applied to the grid of a normally cutoff sawtooth selector stage. Condution of this stage occurs when the sawtooth amplitude reaches a potential slightly less than the bias voltage on the selector. When the sawtooth voltage becomes sufficiently high to cause conduction of the selector, a trigger pulse is produced at the grid of a one-shot multivibrator. The multivibrator output is applied along dual paths to the sawtooth oscillator and discharge tubes to cause the sawtooth flyback. The bias on the selector may be manually varied to change the sawtooth amplitude as will be shown later.

The duration of the sawtooth waveform is adjusted to exactly 107 μ s. The sawtooth selector stage allows a linear rise time from approximately +50 to +215 v (165 v corresponding to the total rise time).

The sawtooth waveform is fed along paralleled paths to the channel selectors, one of which is contained in each channel of the multiplex system. The individual selectors are biased each

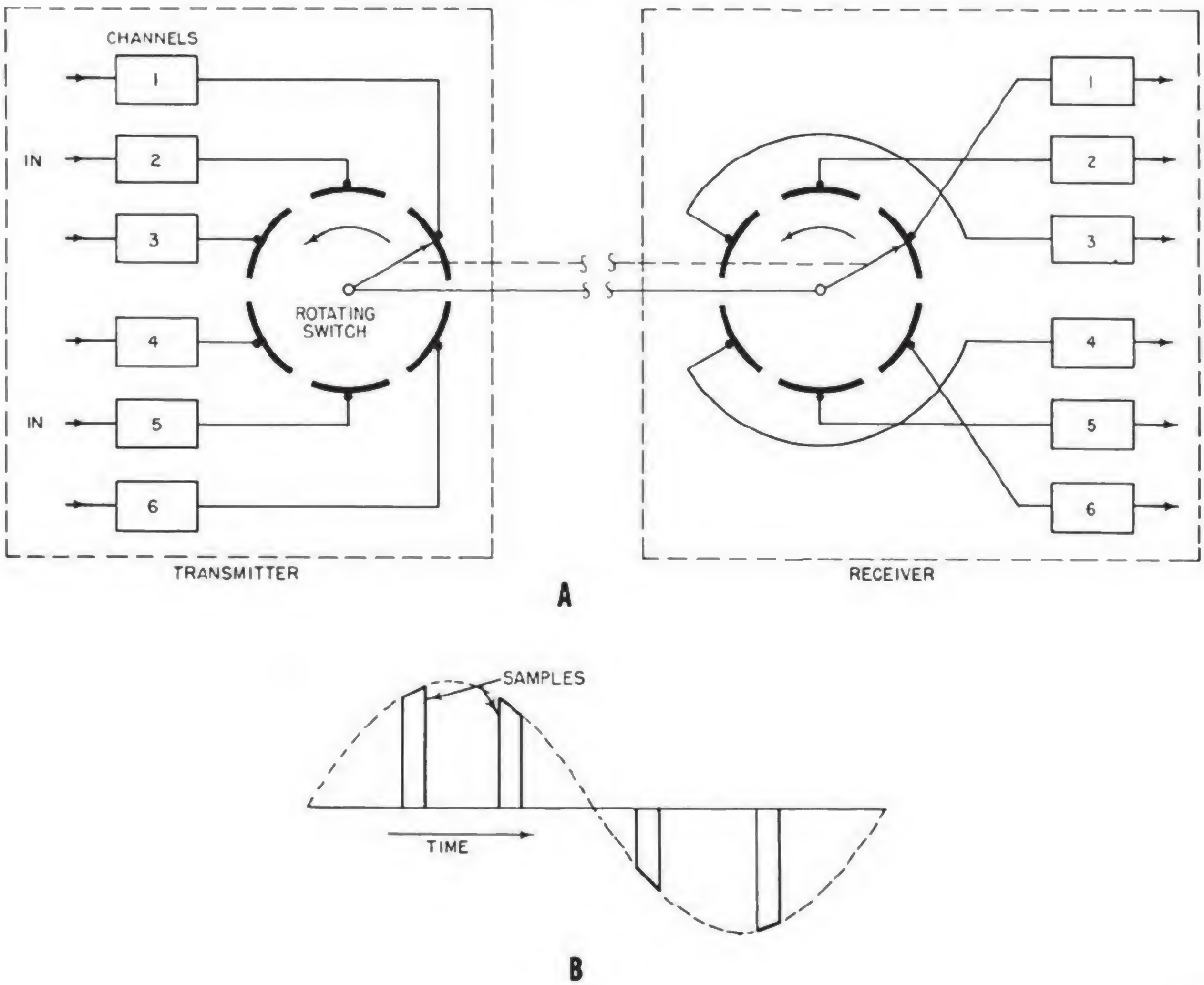

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Figure 15-2.—Basic principle of time-division multiplexing.

at a different level so that they are energized (at different times) by the sawtooth voltage rising at the respective grids.

As each channel selector is energized, it feeds a pulse to a channel modulator, causing this circuit to produce a channel pulse. The channel pulse thus produced (in this channel alone) is then modulated by the incoming audio in accordance with the type of pulse modulation used.

The multivibrator output trigger, which is fed to the sawtooth oscillator and discharge tubes, has a duration of 4.75 μs. Thus, these stages are allowed to conduct for this entire period, a conduction which accounts for the delay between the decay of one sawtooth waveform and the beginning rise time of the next.

Included in the transmitter output is a marker pulse (sometimes called a sync group). These pulses may be of any form but are usually of a nature that makes them easily distinguishable from the modulation pulses at the receiving terminal of the multiplex system. A circuit used to produce a marker pulse will be described presently. The marker pulse (or pulses), along with the total modulation pulses from each channel (in time) presented to the transmitter carrier during one complete cycle of the sawtooth waveform, constitutes a video frame. The relationship between the master oscillator output and

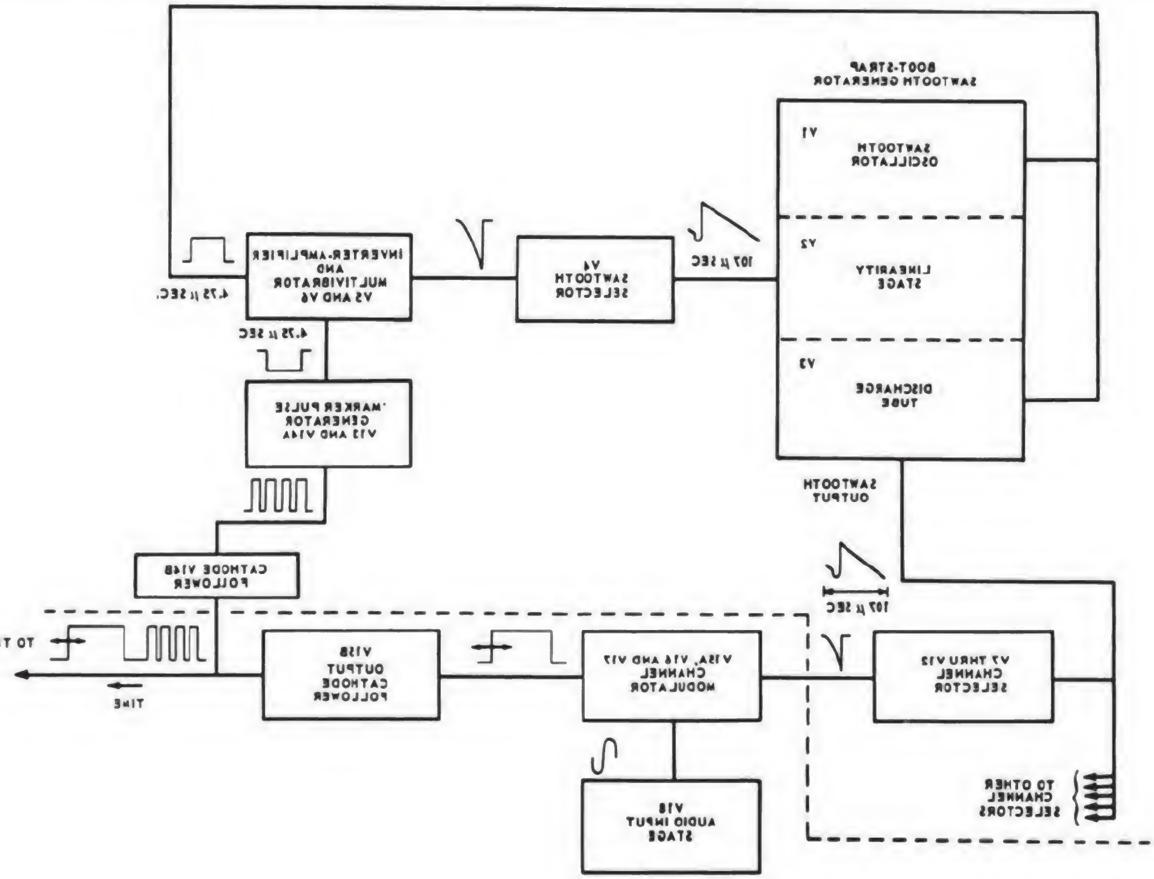

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Figure 15-3.—Time-division multiplex block diagram.

the composite video frame is shown in figure 15-4. The horizontal arrows on the channel pulses represent the possibility of the pulses being placed in different positions with respect to the time that the channel sampling began. This is the principle of pulse position modulation, and is a result of the type channel modulator used. Other types of modulation used are pulse amplitude modulation, pulse width modulation, and pulse code modulation.

The negative gate from the multivibrator (occuring at the same time as the positive pulse that produces the sawtooth decay) gates a Hartley oscillator (marker pulse) circuit to cause the generation of the marker pulses. The sinusoidal oscillator output of the marker generator is acted upon to produce four .5 μs pulses spaced 0.8 μs apart. These pulses are passed through a cathode follower (impedance matching) circuit to the transmitter. Both marker pulses and channel pulses can be coupled along the same line to the transmitter, because each of the pulses is added to the video frame at a different time interval. The primary purpose of the marker pulses is to act as a synchronizing voltage between the receiving and transmitting multiplex terminals.

FREQUENCY-DIVISION MULTIPLEXING

Frequency-division multiplexing (fig. 15-5) is the older of the two methods of multiplexing. In this system, different subcarrier frequencies are modulated by the signals of different channels, transmitted over the same cable (in the case of cable transmission) or on the same radio frequency carrier (in the case of radio transmission), then separated by filters before being demodulated. The total bandwidth required for a frequency-division multiplexing system is the sum of the bandwidths of the individual channels,

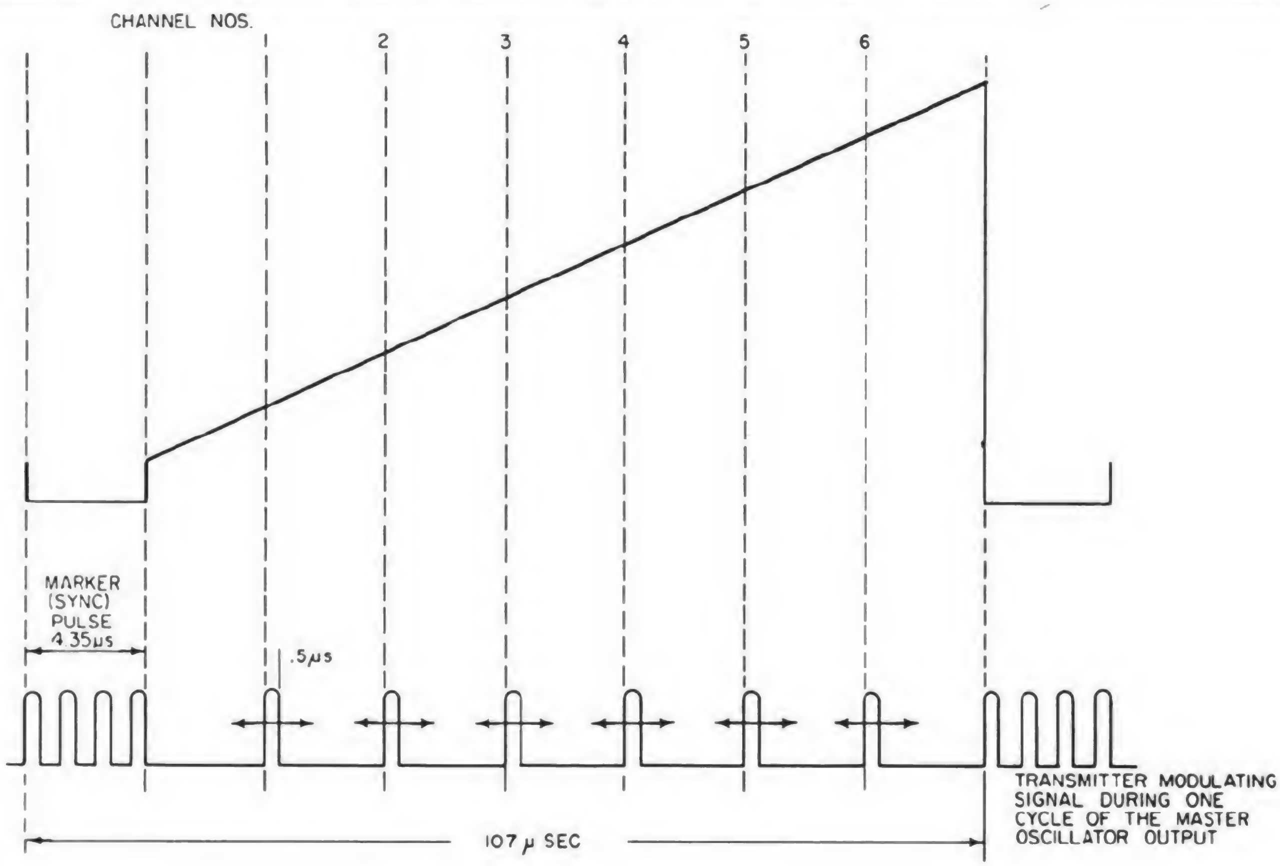

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Figure 15-4.—Relationship of master oscillator output to composite video frame.

plus the sum of the necessary guard-band frequencies between channels.

The resultant signal is each channel will be approximately the same as that which would be produced by the use of a single independent channel, except that nonlinear elements in the system may cause mixing of the various carrier frequencies and crosstalk between channels. For cable transmission, frequency-division multiplexing is a satisfactory method because equipment is available which gives good fidelity, good signal-to-noise ratio, nearly constant gain, and very low nonlinear distortion.

A greatly simplified block diagram of a frequency-division multiplexing system is illustrated in figure 15-5. For simplicity it may be assumed that the signals are transmitted over a cable; nevertheless a radio carrier can be used.

Channels 2 through 6 each employ an oscillator whose frequency is heterodyned with the audio input to the respective channels in a balanced modulator. The sum frequency produced as a result of the heterodyning represents a subcarrier where radio facilities are used. The filter used in each channel allows the passage of the upper sideband to modulate the transmitter r-f carrier. Channel 1 does not employ an oscillator, and therefore feeds its audio input (between 300 and 3,000 cycles) directly to the transmitter.

The bandwidth and position (with respect to frequency) of each of the six channels are indicated at the bottom of the figure 15-5. The total spectrum that may be occupied in this particular example is 19.5 kc.

Only the upper sideband (sum frequencies generated in the balanced modulator) is utilized in each channel. The suppressed carrier frequency is indicated by a dotted line between the various channels. This is the frequency used to generate the sideband indicated to the right-hand

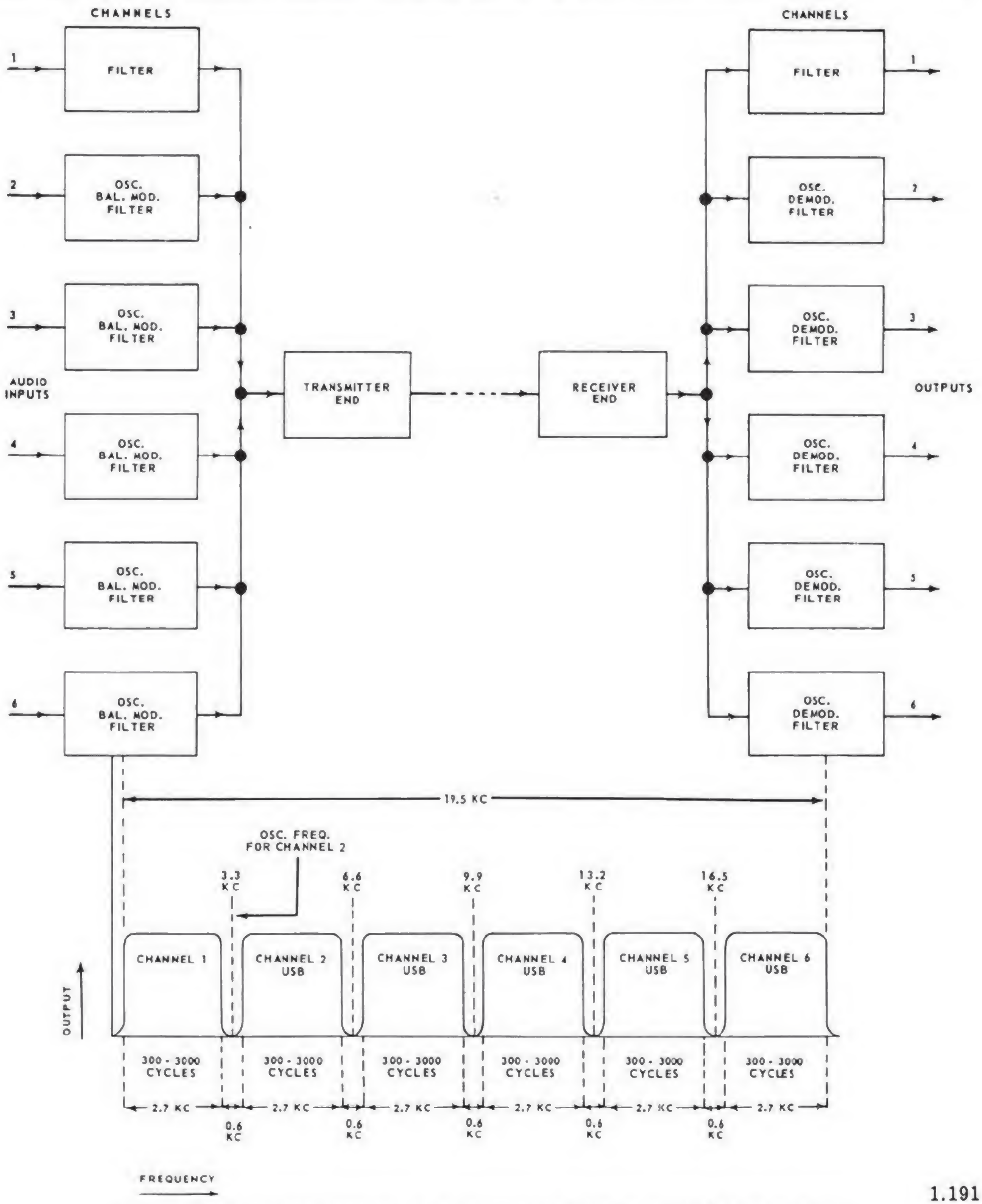

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Figure 15-5.—Block diagram of a frequency-division multiplexing system.

side of the line. For example, 3.3 kc is the oscillator frequency for channel 2. Although the upper side-bands are transmitted in this example, the lower sidebands could have been transmitted just as easily.

The channel 2 circuits at the transmitter and the receiver are used as examples in the block diagram of figure 15-6. For simplicity, a 1-kc tone is assumed to be the channel input.

At the transmitter, the 1-kc signal is fed to the balanced modulator; a 3.3-kc signal is also fed to the balanced modulator from the channel 2 oscillator. The balanced modulator suppresses the carrier and generates upper (4.3 kc) and lower (2.3 kc) sidebands. Only the upper sideband is passed by the channel 2 filter.

The channel 2 demodulator in the receiver accepts the 4.3-kc signal and heterodynes this input with the channel 2 oscillator signal (3.3 kc). The carrier is suppressed, and the two sidebands (7.6 kc and 1 kc) are fed to the channel 2 demodulator filter. The filter passes the 1-kc signal to the reproducer.

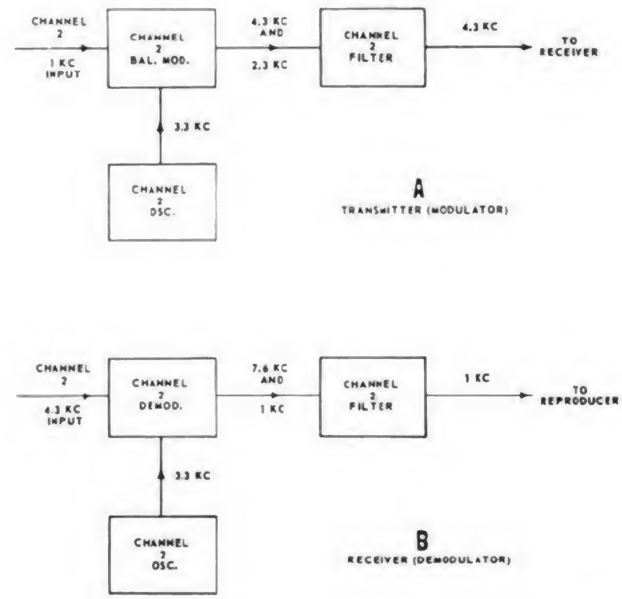

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Figure 15-6.—Block diagram of a modulator and demodulator units.

FREQUENCY-DIVISION SYSTEM AN/FGC-60(V)

Application

The AN/FGC-60(V) Diversity Telegraph Terminal (fig. 15-7) is intended for use on long distance communication links. The terminal provides for the transmission and reception of a number of independent telegraph channels which are simultaneously conveyed over one audio circuit. To insure a high order of reliability, the receiving portion of this system is equipped with dual diversity as well as quadruple diversity facilities.

The AN/FGC-60(V) Non-Diversity Telegraph Terminal is intended for use on long distance communication links were diversity is not required. Prime usages would be on cable installations, land-line, microwave, and the like. This terminal provides for the simultaneous transmission and reception of a number of independent telegraph channels.

Description

The AN/FGC-60(V) is a fully transistorized 16-channel transmit and dual diversity receive frequency division multiplex system further capable of 8 quadruple diversity receive channels. All the channels can be individually operated and utilize the audio frequency shift keyed method of signaling.

Structurally all basic units within the cabinets are of modular type, designed for high reliability and simplicity of operation. The modular concept is not. restricted to the individual units making up the system. The system itself is conceived as a building block capable of expansion by the addition of other such systems to handle greater traffic loads. As an example, by the use of the group heterodyning equipment, two Model AN/FGC-60(V) systems can provide for 32 independent data circuits in a 6 KC bandwidth. In the case of an independent sideband transmitter, it is possible to place one 32-channel system on the lower sideband to accommodate a total of 64 channels. It is, furthermore, possible to substitute for any 16-channel group an ordinary voice communication circuit.

While the AN/FGC-60(V) system, in its standard configuration, provides for 100 wpm telegraph channels, the modular structure of the system makes it readily adaptable to other forms of communications. A simple change of plug-in submodules permits change of frequency assignment, frequency shift, and maximum channel speed.

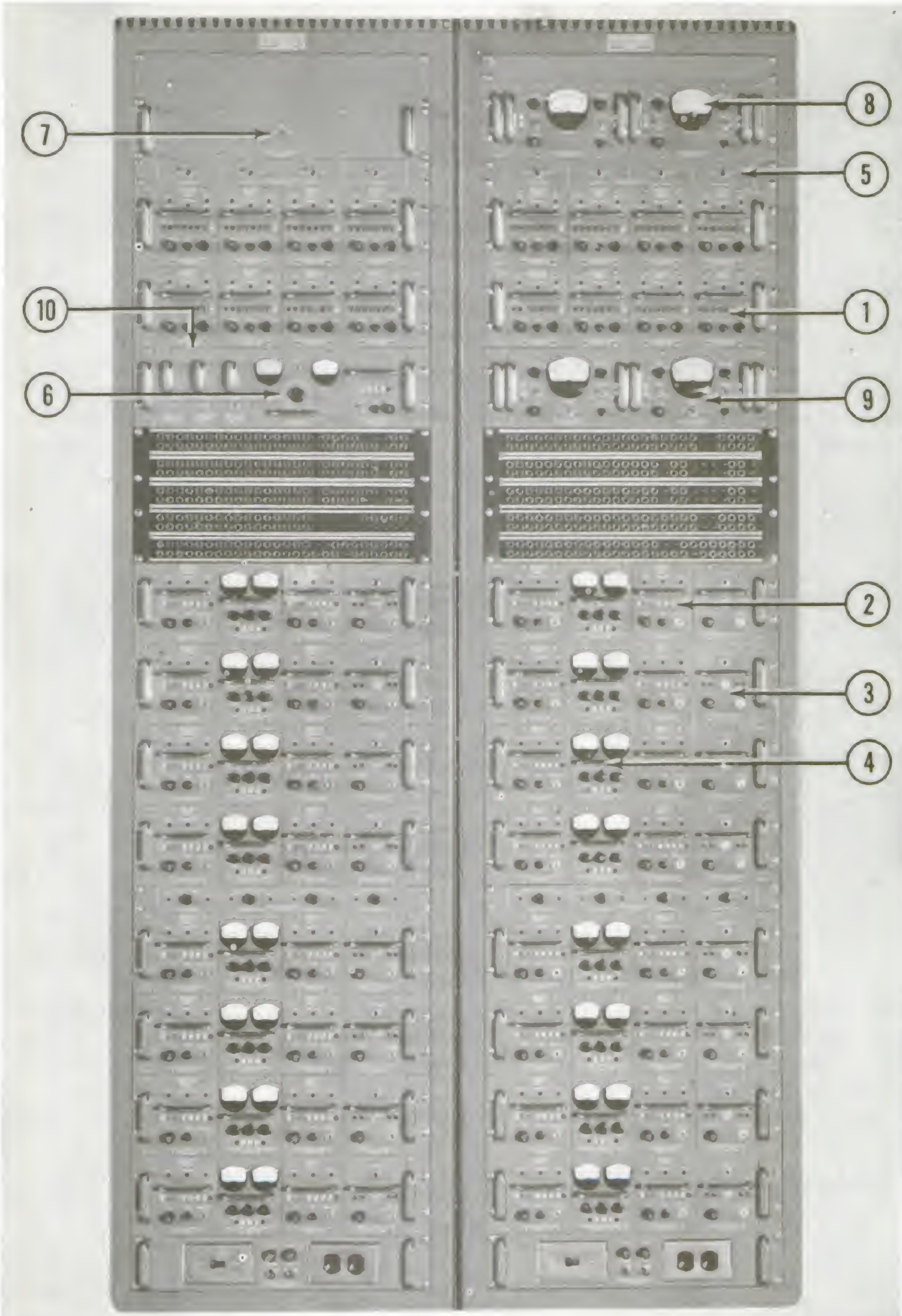

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Figure 15-7.—Diversity Telegraph Terminal AN/FGC-60(V).

In its standard configuration with twinning selector (to be explained later) set at Dual Position, the AN/FGG-60(V) provides for dual diversity receiving facilities. Any two diversity signals (frequency diversity, space diversity or polarization diversity) can be used with the Diversity Comparator. It is equally possible when needed, to omit the diversity feature or by repositioning of the twinning selector, to extend the diversity function to quadruple diversity.

The AN/FGC-60(V) system is a completely selfcontained telegraph terminal. The cabinet is equipped with all signal and power distribution wiring. Complete patching facilities are also an integral part of the system. Line amplifiers, a metering panel, and group modulation equipment are additional features of this telegraph system.

The completely transistorized circuitry has made it possible to considerably reduce the size and weight of the system in comparison with comparable vacuum tube equipment, and to further drastically reduce the power consumption and increase the reliability of performance.

ELECTRICAL SYSTEM SPECIFICATIONS.—The AN/FGC-60(V) Diversity 16-channel system consists of two independent 8-channel assemblies, each housed in a separate equipment cabinet or rack. The complete system is normally supplied with the following channel distribution:

Sub-system, "Unit A": Contains channels 1 to 8 inclusive.
Sub-system, "Unit B": Contains channels 9 to 16 inclusive.

The sending signal sense of all odd numbered channels is "Positive," while the sense of all even numbered channels, is "Negative." In a positive channel, a MARK telegraph input will be transmitted as a tone frequency above center reference frequency, and a SPACE telegraph input will be transmitted as a tone frequency below center reference frequency. In the negative signal sense the reverse holds true.

The channel frequency assignments are as follows:

Adjacent channel separation:	170 cps
Frequency shift:	42.5 cps
Maximum speed:	100 wpm teletype

SUB-SYSTEM UNIT	CHANNEL No.	CENTER FRE-QUENCY (cps)	SENDING SIGNAL SENSE
A	1	1785	+
A	2	425	-
A	3	1955	+
A	4	595	-
A	5	2125	+
A	6	765	-
A	7	2295	+
A	8	935	-
B	9	2465	+
B	10	1105	-
B	11	2635	+
B	12	1275	-
B	13	2805	+
B	14	1445	-
B	15	2975	+
B	16	1615	-

FREQUENCY SHIFT KEYER.—The keyer (#1 fig. 15-7) is used on communications circuits such as telegraph systems, telemetering circuits, and single sideband radio links. In these applications it provides the transmitting terminal frequency shifted signals in the audio spectrum. The frequency shift keyer can be paralleled with other like transmitters on the same audio circuit, resulting in a multichannel frequency shift (F/S) tone system. Any number of channels and channel speeds can be provided, limited only by the available bandwidth of the circuit.

The keyer is a completely transistorized unit, using only semiconductors instead of vacuum tubes and/or electro-mechanical relays. The use of transistors has made it possible to utilize novel circuit concepts in the design of the F/S Tone Keyer. This new circuitry permits the generation of frequency shifted signals with greater precision than heretofore possible.

The frequency shift keyer is a completely self-contained unit, including its own power supply and monitoring facilities. Since the

units dissipate but negligible heat, and since all adjustments and controls are available on the front panel, such groups of four transmitters can be stacked with other groups of like transmitters—much like building blocks, without need for separation panels. This permits the maximum utilization of front panel space and up to 48 channels can be readily mounted into one standard relay rack. In such multichannel systems, all transmitters are alike and plug-in type frequency determining networks and channel filters determine the channel frequency, frequency shift, and channel speed assigned to each transmitter.

FREQUENCY SHIFT CONVERTER.—The converter (#2 fig. 15-7) is used on communication circuits such as tone telegraph systems, telemetering circuits, and single sideband radio links. In these applications, it provides the receiving terminal (which demodulates) with great precision frequency-shifted signals in the audio spectrum. The receiver can be paralleled with other like receivers on the same audio circuit, resulting in a multichannel F/S tone system. Any number of channels and channel speeds can be provided, limited only by the available bandwidth of the circuit.

ELECTRONIC TRANSISTOR SWITCH.—The switch (#3 fig. 15-7) is one of a group of output coupling devices intended for use with the F/S Converter or other equipment designed to operate therewith. It is used where complete isolation is required, such as is normally provided by an electro-mechanical relay, but where there are objections to the use of such a relay because of speed limitations, maintenance requirements, or similar reasons, and where it is necessary to operate into lines equipped with 120 volt line batteries or where it is desirable that the line battery be part of the output coupling devise. The electronic switch, in addition to providing complete isolation and self-contained line battery, which may or may not be utilized, is also completely protected against accidental faulty connections in the output circuit.

CHANNEL SELECTOR SIGNAL DISTRIBUTION PANEL.—This panel (not included in the model shown in figure 15-7) is specifically designed to operate in conjunction with pairs of Signal Comparators. The distribution panel is so constructed as to enable the combining of the outputs of eight dual diversities into four quadruple diversities. The unit provides the feature of switching from quadruple to dual diversity for individual pairs of diversity.

SIGNAL COMPARATOR.—The comparator (#4 fig. 15-7) is intended for use on frequency shift circuits where the additional reliability of receiver diversity is required, such as long distance HF circuits, scatter communication links, and the like. In these applications, the signal comparator is used in addition to two F/S conversion units. Its function is to continuously compare the signal quality of the two receiving channels, to suppress the one having the poorer signal to noise ratio, and to supply an output signal having substantially the quality of the better channel at a given time.

The design of the signal comparator permits it to be used directly with any of the conventional diversity schemes such as frequency, space, or polarization diversity. The two diversity channels may operate either on the same or at different frequencies. This flexibility may result in substantial savings in associated equipment needed to make up a dual diversity receiving bay.

TRANSMITTER TWINNING PANEL.—The twinning panel (#5 fig. 15-7) is specifically designed to operate with pairs of F/S Keyers. It is designed to be capable of handling eight F/S Keyers in four independent pairs. The telegraph systems are normally wired so that each transmitter can be keyed independently. The transmitter twinning panel permits the operator (by merely switching) to slave the even transmitters so that they will be keyed with the adjacent odd channel information. This is a prime requirement during operation with frequency diversity.

METER PANEL.—The meter panel (#6 fig. 15-7) is designed to operate in conjunction with telegraph systems, in particular, the AN/FGC-60(V). The unit is capable of measuring VU levels as well as d-c currents. The VU level section features an input isolation transformer and has no appreciable loading effect on the circuit being measured.

SIGNAL DISTRIBUTION PANEL.—This panel (#7 fig. 15-7) provides for the connection of all external signal wires to the system and for their distribution within this system. This unit

provides the terminal connection and distribution facilities for an 8 channel transmit-dual diversity received tone telegraph system. Three separate tone circuits are provided: one transmitting and two receiving circuits, all equipped with 600/600 ohm line isolation transformers. The transmitting circuit is also equipped with a 600 ohm "T"-Attenuator to facilitate adjustment of the aggregate tone level. For the incoming and outgoing d-c circuits, the unit serves merely as a connection and distribution center. All tone and d-c circuits of the panel are directly wired to the patch field and hence distributed to the units of the system.

MULTIPLEXER.—The multiplexer (#8 fig. 15-7) is fully transistorized equipment and is intended for use with single sideband and independent sideband (twin channel) radio circuits. Its purpose is to combine two voice frequency circuits into one channel for transmission over the air. This function is accomplished by means of frequency division multiplexing, whereby the radio bandwidth from 300 to 6000 cps is divided into independent channels, each with a bandwidth of 375 to 3025 cps. When used with independent sideband transmitters (twin channel), two multiplexers and two demultiplexers are needed to provide for four independent voice frequency circuits. The independent voice frequency circuits derived from the multiplexer and demultiplexer cam be utilized for voice, facsimile, or general data transmission. As a specific example, one of the voice frequency circuits can carry the signals of a 16-channel teletypewriter system or that of a high speed data terminal. While such teletype or high speed signals are carried on one or more of the available frequency bands, the remaining voice bands can be utilized for facsimile or telephone service.

DEMULTIPLEXER.—The demultiplexer (#9 fig. 15-7) is a fully transistorized equipment intended for use with single sideband and independent sideband (twin channel) radio circuits. Its purpose is to separate two voice frequencies that were combined by the multiplexer. This function is accomplished in the opposite manner from which the multiplexer combines the channels (see above).

AUDIO FREQUENCY AMPLIFIER.—The audio frequency amplifier (#10 fig. 15-7) is intended for use on the multi-channel telegraph systems where it is desirable to control or raise the level of the incoming common tone line. The audio frequency amplifier is applicable for all configurations of the AN/FGC-60(V). The amplifier features input and output transformers and a nominal input and output impedance of 600 ohms.

System Functional Block Diagrams

Figure 15-8 is a functional block diagram of both the send and receive circuits of the AN/FGC-60(V) in non-diversity.

DEMULTIPLEXING

As may be expected, the problem of demultiplexing is very similar to that of multiplexing. A simplified block diagram of a demultiplexing system is shown in figure 15-9. This system shows only three channels, although any number may actually be used as was noted earlier.

The output from the receiver terminals (or the signal from the cable if a cable transmission system is used) will have the waveshape of the composite video frames as they were formed by the multiplexing unit. These signals will usually be amplified to a power level capable of operating the associated demultiplexing equipment as shown by the block in the upper left-hand portion of the diagram.

In order to reconstruct the intelligence from each channel, it is necessary to have a time base that is exactly the same as that of the timing circuit in the multiplexing system. This is accomplished, in the system shown, by using an integrating circuit, labeled "sync separator" in the block diagram. This sync separator is designed to detect the "sync group" of the composite wave-form, providing a pulse output that triggers a sawtooth generator. The oscillation frequency of the sawtooth generator is then exactly the same as that used in the timing circuit of the multiplexer.

The output of the sawtooth generator is then fed to each of the channel selectors. These blocks represent a circuit that can be adjusted to "fire" (and give out a signal) when the sawtooth wave is at the desired amplitude. Since the sawtooth wave is linear with respect to time, the channel selectors then fire at the desired instant of time, which is adjusted to

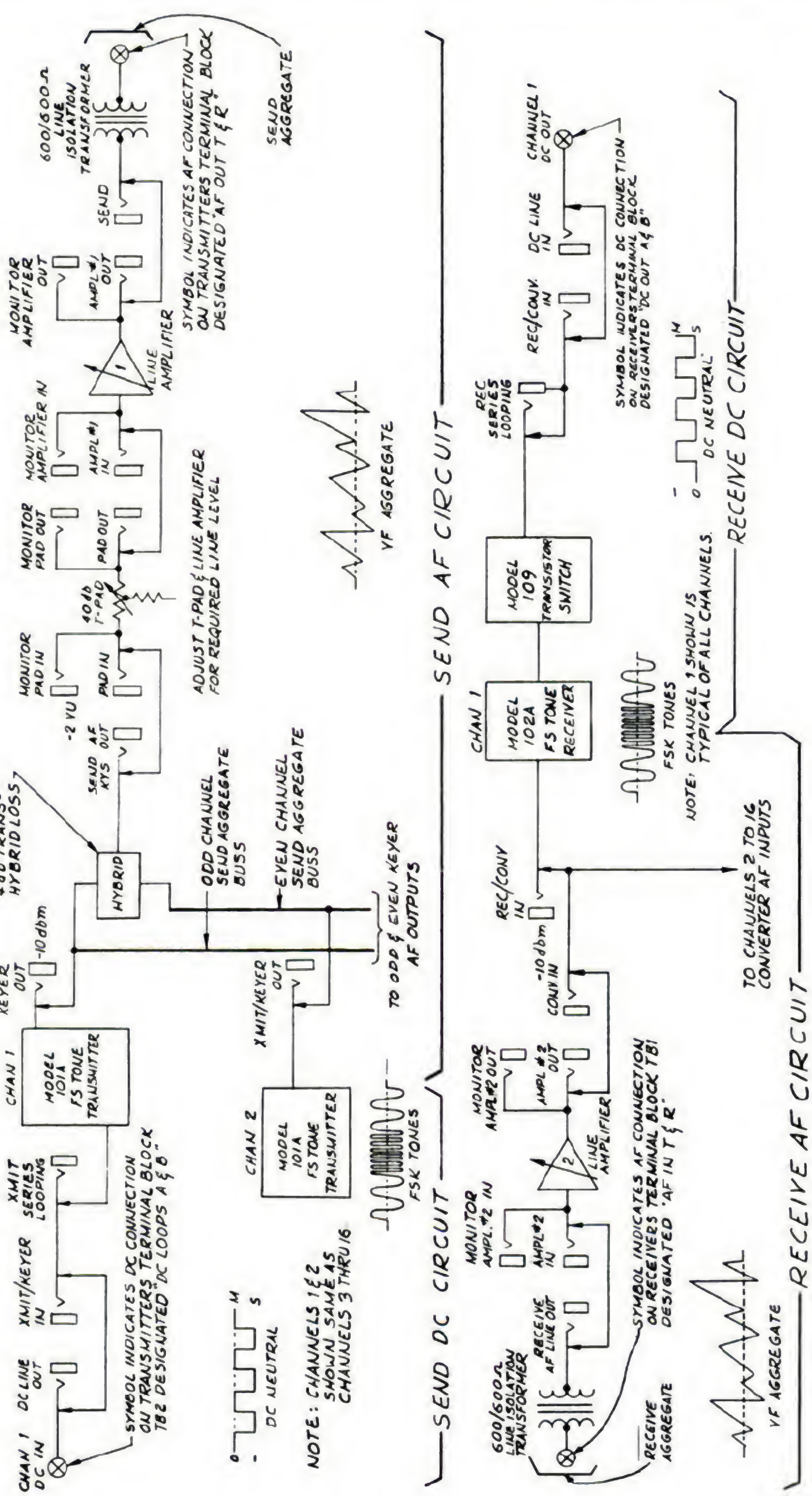

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Figure 15-8. —AN/FGC-60(V) Functional block diagram.

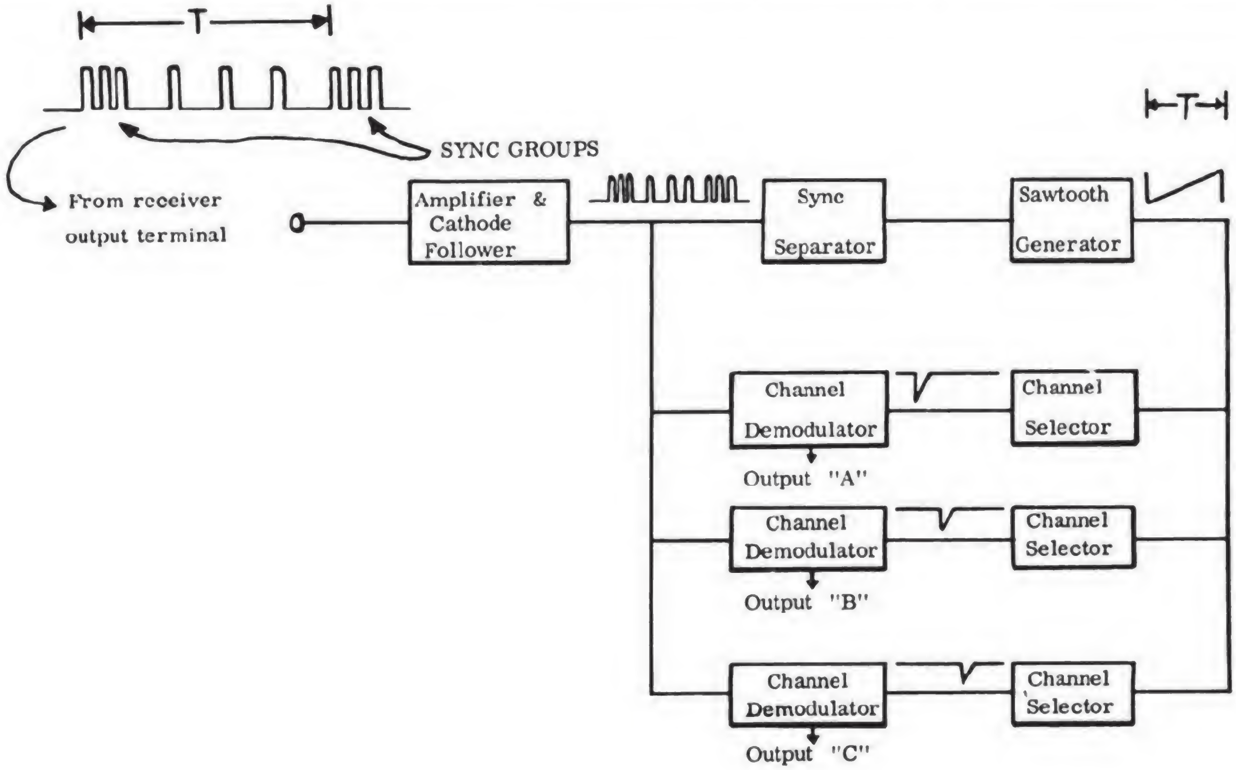

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Figure 15-9. —Block diagram of demultiplexing.

correspond to the beginning of the sampling period in the multiplexing system.

The output of each channel selector is sent to one input of a channel demodulator. Another input of the channel demodulator receives the composite waveform. Each block labeled channel demodulator then represents the circuitry necessary to sample the composite waveform for a specified period of time beginning with the signal seen during that sampling period back into the audio or intelligence information that was fed into the channel modulators in the multiplexing system.

CHAPTER 16

TELETYPEWRITER AND ASSOCIATED EQUIPMENTS

TELETYPEWRITER SIGNALS AND THE TAPE CODE

To see how intelligence is sent over teletypewriter, one of the simpler devices for electrical communications—the manual telegraph circuit—is first considered. This circuit, shown in figure 16-1 includes a telegraph key, a source of power (battery), a sounder, and a movable sounder armature. If the key is closed, current flows through the circuit and the armature is attracted to the sounder by magnetism. When the key is opened, the armature is retracted by a spring. With these two electrical conditions of the circuit—closed and open—it is possible, by means of a code, to transmit intelligence. These two conditions of the circuit may be thought of as MARKING and SPACING. Remember: marking occurs when the circuit is closed and a current flows; spacing occurs when it is open and no current flows.

When a circuit operates on current and no-current basis, as in figure 16-1, it is called a NEUTRAL circuit. This type is generally used to operate teletypewriters, although the Navy's machines sometimes operate on a line condition called POLAR OPERATION. This refers to the system whereby marking signals are formed by current impulses of one polarity and spacing signals by current impulses of equal magnitude but opposite polarity.

If a teletypewriter signal could be drawn on paper, it would resemble figure 16-2. This

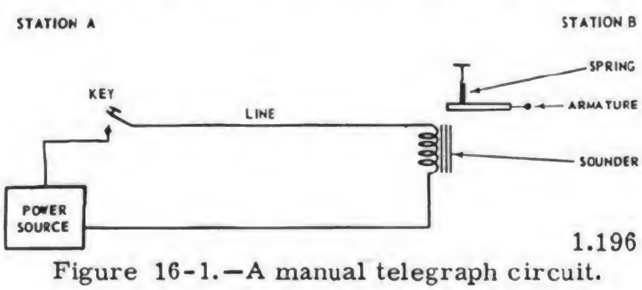

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Figure 16-1.—A manual telegraph circuit.

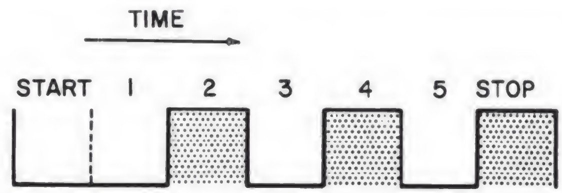

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Figure 16-2.—Mark and space signals in the teletypewriter character R.

is the code combination for the letter R. Shaded areas show intervals during which the circuit is closed (marking), and the blank areas show the intervals during which the circuit is open (spacing). There are a total of seven units in the signal. Five of these are numbered, and are called INTELLIGENCE units. The first and last units of the signal are labeled START and STOP. They are named after their functions: the first starts the signal and last stops it. These are a part of every teletypewriter; the START unit is always spacing and the STOP unit is always marking. This method of teletypewriter communication—the so-called START-STOP method—gets its name from these units.

The start-stop method keeps teletypewriter machines and signals in synchronization with each other. With this method the selecting mechanism in the receiving machine comes to a complete stop after each character.

Different characters are transmitted from the keyboard by an automatic process that selects various combinations of marking and spacing in the five intelligence units (fig. 16-3). You can see that the mark and space units match the holes and blank spaces on the tape. This is because holes in the tape allow the transmitter-distributor pins to rise, sending a marking pulse. No holes mean no pulses—that is, spacing intervals. The machine, without benefit of tape perforations automatically takes care of start and stop elements.

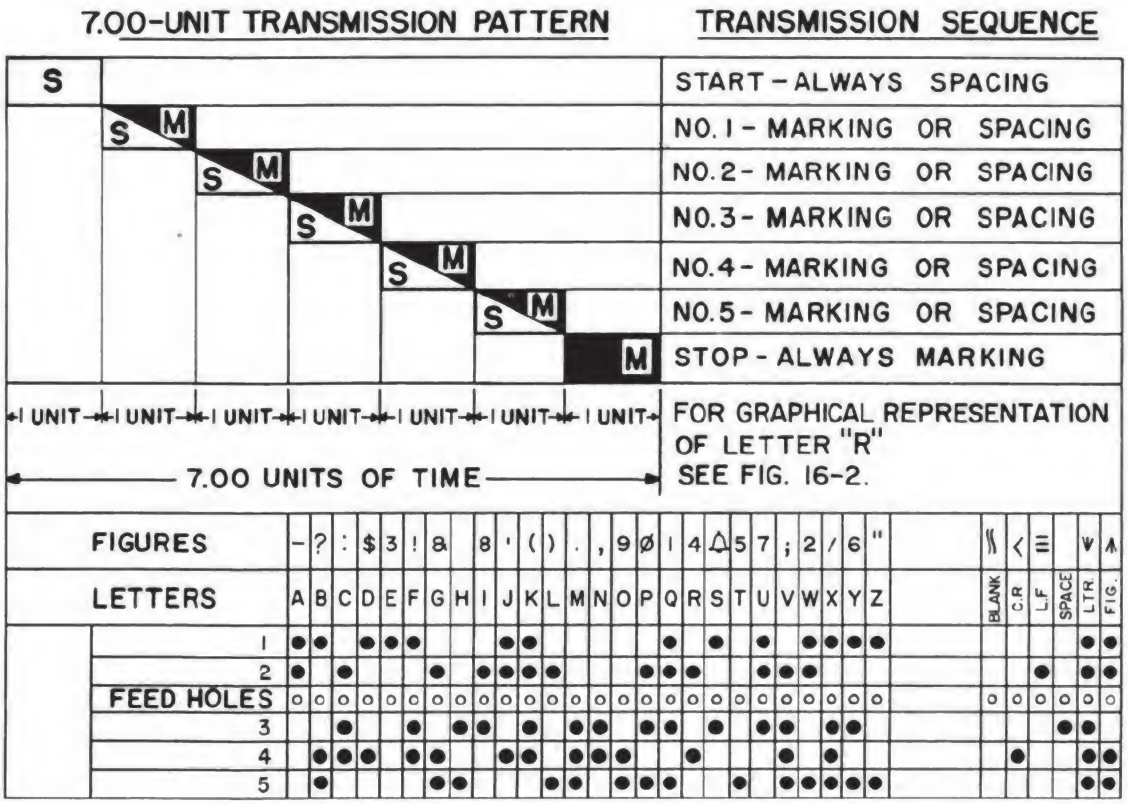

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Figure 16-3.—A teletypewriter signal code.

A total of 32 combinations can be obtained from the five intelligence units, but by using upper and lower case, the number of characters obtainable is nearly doubled. When a teletypewriter printing mechanism has been shifted to upper case as a result of having received a FIGS shift character, all succeeding characters received prior to a LTRS shift character will print in upper case—as numerals and punctuation marks. The machine does not, however, make such double use of all 32 possible combinations, since six are used for the functions of carriage return, line feed, figures shift, letters shift, space, and for one normally unused blank key. This leaves 26 of the 32 that can be employed in both upper and lower case. When the six special functions are added, the total is 58, which is the number of characters and functions that can be sent from a teletypewriter keyboard.

Examine figure 16-2 once more. This is theoretically a perfect signal. The quality of each element remains the same during its transmission, and the shift from marking to spacing (and vice versa) is instantaneous. These changes are called TRANSITIONS. They occur at the beginning and end of each of the solid blocks. Some are mark-to-space transitions, and others are space-to-mark transitions. For some other character combination a transition may occur between "start" and intelligence unit 1, but in any transmitted character there can be only two, four, or six transitions. Every combination includes five elements that carry the intelligence, each of which may be either marking or spacing. The intelligence elements are preceded by a start element (always spacing) and are followed by a stop element (always marking). Thus each combination consists of 7.00 units of time (referred to as a 7.00 unit transmission pattern). The start and stop elements provide for mechanical synchronization between the transmitting and receiving equipment. As can

be seen in figure 16-3, all five elements are marked in the "letters" code. The "blank" code is comprised of five spacing elements.

The telegraph circuit in figure 16-1 can be converted to a simple teletypewriter circuit by substituting a transmitting teletypewriter for the key at station A, and a receiving teletypewriter for the sounder at station B.

DISTORTION

An ideal teletypewriter circuit reproduces signals at the receiving end exactly as they are impressed at the sending end. Unfortunately this seldom happens under actual operating conditions, for signal units have a way of lengthening and shortening as they travel. This lengthening and shortening of marks and spaces occuring during transmission reduces the quality of the signal, and is called distortion. Distortion in teletypewriter signals may be characteristic distortion, fortuitous distortion, or bias. The componenets of distortion cannot be briefly defined. They are the result of a variety of conditions in the circuit: crossfire, power interference, the tail of one signal interfering with another, and so on.

ORIENTATION RANGE FINDER

In figure 16-2 illustrating the signal for the letter R, each unit or element is perfect in every respect. To print the letter R, the selection mechanism could be set to operate on any 20-percent portion of each unit, and perfect copy would result. Under actual conditions, a signal is never this perfect, nor is a teletypewriter expected to operate over the entire range of the unit. Rarely will more than 70 percent of each unit be usable by the selecting mechanism. This means that the selection point must be positioned so that the best portion of the lement will be used by the selecting mechanism.

Each teletypewriter is equipped with an orientation rangefinder that allows the machine to be set at the range of best reception. The rangefinder is a device consisting of a scale and a finder knob. (The finder and its scale are illustrated in figure 16-4.) Degrees on the scale—0 to 120 —divide the first unit of the signal only, not the entire signal. When you adjust the finder knob you shift the selection point of the first unit with respect to the starting unit. Figures 16-5A and 16-5B illustrate this. Since all other units of the signal follow a 22-millisecond interval, this amounts to adjustment or orientation of the entire signal to the start pulse.

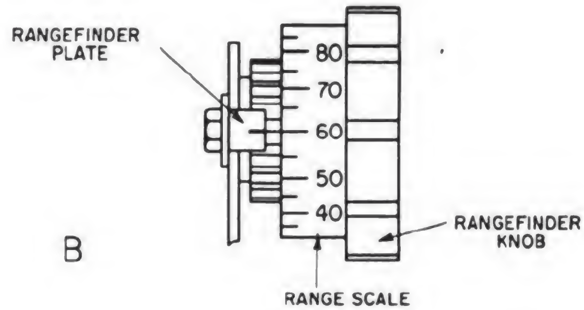

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Figure 16-4.—The orientation rangefinder.

Since the scale goes up to 120 percent of one unit, you can shift far enough so that the selection interval moves entirely off the unit. If the signal were perfect, you could still shift the finder far enough to produce errors. The object is to place the selection interval on that portion of the unit that will give the selecting mechanism a maximum margin of safety while selecting that unit and the four which follow. With the selection point midway between the transitions, there is the least chance of error.

To determine the range limits, the finder knob is adjusted at the two extreme positions—at the lower and the upper end of the scale. In each case observations are made of the typed record and a reading is taken when about one error is typed per line of copy. This means about one error in 72 characters. Orientation ranges on properly adjusted teletypewriters for different degrees of signal distortion are as follows:

	Points
Very little distortion	80
Moderate distortion	60 - 70
Average distortion	50
Large distortion	Less than 40

The orientation range limits with practically perfect signals and a teletypewriter in good condition should be 15 and 95. In this case, best operating results will be obtained when the finder knob of the receiving teletypewriter is set at the midpoint (55) of this range.

Actually, the orientation range is determined twice: First, range of the machine (local range) is determined, then range of the machine

when connected to the line (line range) is determined. Setting of the finder knob is the midpoint of the sum of these two ranges.

The orientation range is obtained locally by using keyboard signals. Normally, the letters R and Y are used since they give a complete reversal of impulses. R is S-M-S-M-S and Y is M-S-M-S-M. (Other characters can be selected which would also give a complete reversal of impulses.) If the range is not less than about 70 percent (from about 20 to 90 on the scale) it may be assumed that the machine is satisfactory.

The difference between the range determined by local test, and the corresponding range obtained when receiving signals over a line, represents the reduction in margin due to signal distortion. The reduction is a direct measure of total signal distortion.

The manner in which typed errors occur in the neighborhood of the orientation limits may give indication of the nature of the distortion. If limits are fairly definite—the copy changes from good to bad when the rangefinder is moved only a small distance—bias, or distortion due to speed variations or faulty apparatus, is present. If there is a certain range at each limit over which certain characters are consistently in error, this is due to characteristic distortion. If limits are not definite—that is, there is a range over which errors occur, and errors do not occur consistently on certain characters—this is an indication of fortuitous distortion. As a general rule, characteristic and fortuitous distortion cause reduction of the range at both limits. On the other hand, bias affects one range more than the other. Marking bias reduces the upper range limit, and spacing bias reduces the lower range limit.

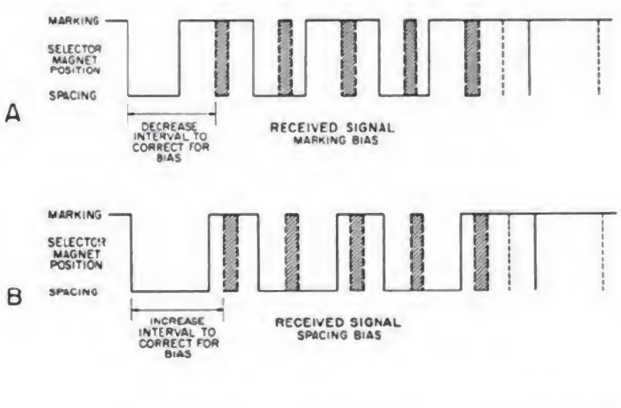

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Figure 16-5.—Received signal marking and spacing bias.

Maintenance men sometimes test distortion tolerance of a teletypewriter by applying predistorted signals. This predistortion ranges from zero to 40 percent. A well-adjusted machine will type correctly when signals from a test set are distorted as much as 35 percent.

Rangefinding a teletypewriter is not an everyday occurrence. Usually it's an operation performed in conjunction with maintenance of the machine. Unless something goes wrong with the circuit, rangefinding will be done during overhaul. When rangefinding a machine, care must be taken that the machine is in good adjustment and range limits are read accurately.

MODEL 28 TELETYPEWRITER EQUIPMENT

GENERAL

The teletypewriters described herein are electromechanical apparatus which serve as self-contained message originating and/or receiving centers. They are used to exchange printed and tape-perforated messages between two or more stations connected by wire or RATT telegraph channel.

The Automatic Send-Receive (ASR) Teletypewriter Set (figure 16-6A) will receive messages electrically from the telegraph channel and print them on page-size copy paper. With page-printed monitoring, it will electrically transmit on the channel messages which are originated either by perforated tape or keyboard operation. It will mechanically prepare perforated and printed tape for separate transmission with or without simultaneous electrical transmission and page-printed monitoring. In addition to these functions it will receive messages electrically from the channel and record them on tape in both perforated and printed form.

The Keyboard Send-Receive (KSR) Teletypewriter Set (figure 16-6B) will receive messages electrically from the telegraph channel and print them on page-size copy paper. It will electrically transmit on the channel messages which are originated by keyboard operation and monitor the message on page-size copy paper. The KSR Set may be housed in either the floor model cabinet or rack mounted.

The Receive-Only (RO) Teletypewriter Set (figure 16-6C) will receive messages electrically from the telegraph channel and print

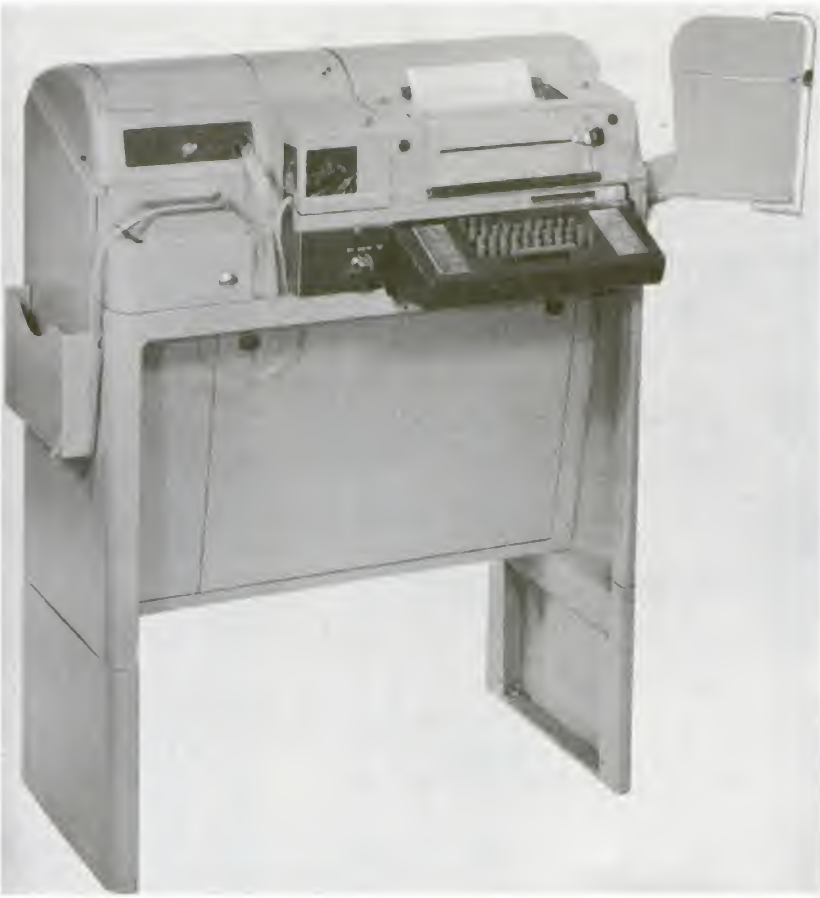

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Figure 16-6A.—Automatic Send-Receive (ASR) Set (on sub-base)

1. 361. X
Figure 16-6B.—Keyboard Send-Receive (KSR) Set (rack mounting).

them on page-size copy paper. The RO Set is housed in a cabinet for rack mounting.

The typing units used in these Sets are arranged to handle rolled single copy or multi-copy paper, eight and one-half inches wide. A paper winder (PW) is used, where needed, to automatically wind the printed copy on a cylinder as it emerges from the cabinet.

Tape used for either perforating and printing messages for transmission or for recording incoming messages is 11/16 inch wide and is supplied in 8 inch rolls on a two-inch spool.

Transmission between stations is accomplished electrically by use of the five-unit start-stop signaling code, which utilizes a 7.00 unit transmission pattern. The equipment is wired for 0.035 ampere polar operation.

The equipment may be geared to operate at 75 baud (approximately 106 words per minute) or 45.5 baud (approximately 65 words per minute) as determined by the requirements of the set.

AN/UGC-13 TELETYPEWRITER SET

The sheet metal cabinet (see figures 16-6A and 16-7) is designed to house all the components of the Automatic Send-Receive (ASR) Set. The upper portion contains the keyboard, typing unit, typing reperforator, transmitter distributor, transmitter distributor base, electrical service assembly and motor, also the auxiliary typing reperforator, typing reperforator base and motor. Where power factor capacitors are necessary for the motor units they are mounted on the rear wall of the lower compartment, accessible by opening the front panel.

A dome extending completely across the cabinet is hinged at the rear and latched at

1.362X
Figure 16-6C.—Receive-Only Set (rack mounting).

both sides. It is partially raised by two torsion bars when the latches are released. Small doors in the dome provide access to components without raising the dome. At the top right end of the dome, a door provides access to the rear of the typing unit for changing copy paper. A window in front of that door affords a view of the platen, type box, and line being type. The rear of the window is a straight edge for tearing off printed copy. The window may be opened for straightening paper or changing ribbon. A dome door in the center of the cabinet can be opened for reloading the typing reperforator tape container. A hinged segment of the front of the cabinet can be raised for access to the typing reperforator. When closed, this segment has two windows for viewing the perforated tape with the window at the left serving as a tape cutoff guide. A door at the left of the dome provides access to the auxiliary typing reperforator.

The dome is wired to include a 6-volt copy and indicator lamp circuit. Associated with this circuit is a transformer and a three-position toggle switch which is accessible in the center of the cabinet dome when the right dome door is open. Also mounted on the dome are a lamp for illuminating copy in the typing reperforator, two lamps for the typing unit copy paper, and a margin indicator or end-of-line lamp.

Terminal boards on which all apparatus wiring terminates are located across the back panel of the cabinet.

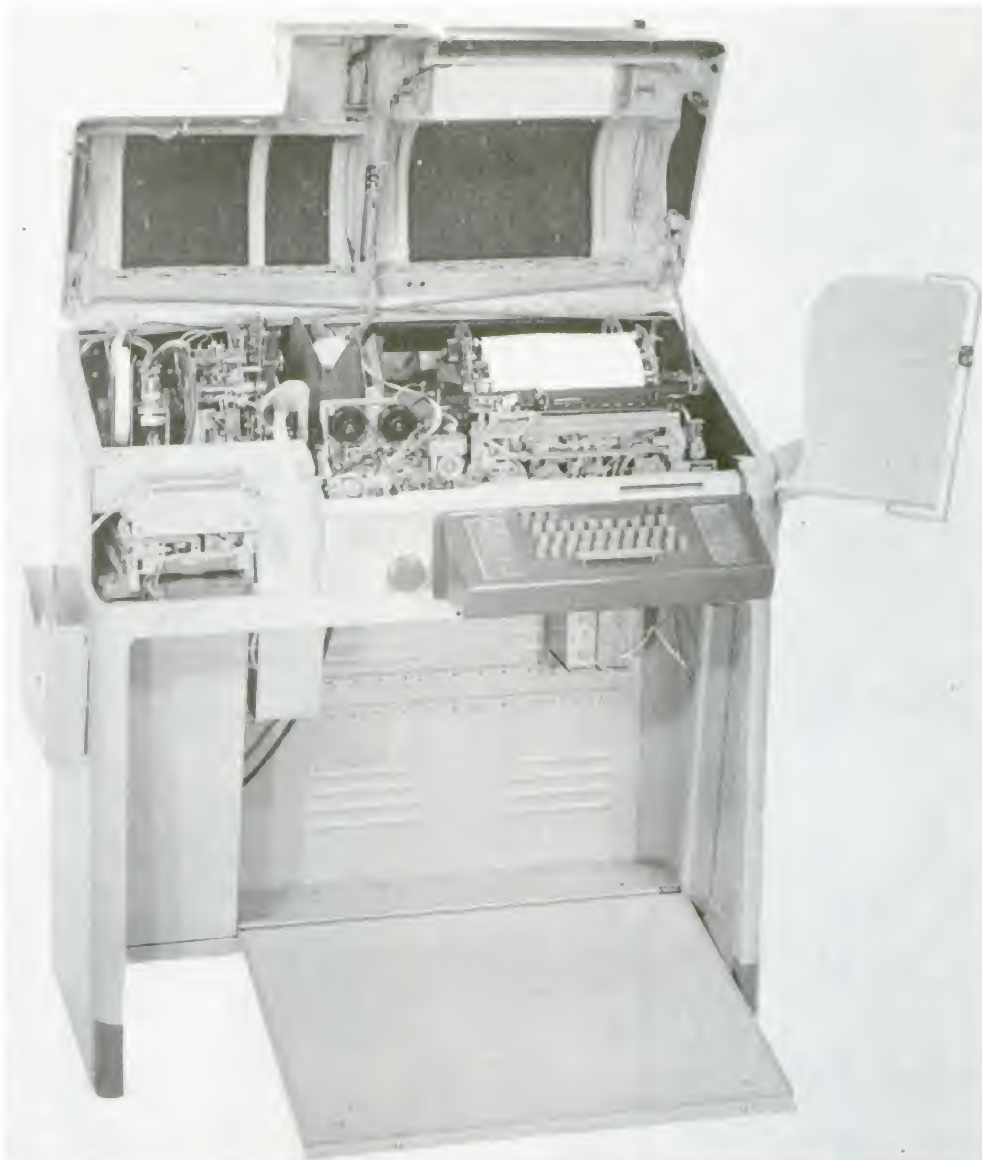
A shelf separates the upper portion from the lower portion of the cabinet and serves as a mount for most of the components. Incoming signal and power lines, and cradle assembly are mounted on the top side of the shelf. The cradle rests on vibration mounts. A switch lever for controlling the power switch on the electrical service assembly extends under the cradle and protrudes at the right of the keyboard. The cabinet may also be modified for "stand-up" operation by addition of the sub-base illustrated in figure 16-6A.

Typing Unit

The typing unit, (figure 16-8) is a component of each of the sets, incorporates the necessary electrical and mechanical elements to translate the signaling code combinations into mechanical actions which print the messages and perform functions incidental thereto. Code signals are applied to a two-coil magnet associated with a selecting mechanism which interprets the signals and controls the motion involved in typing a character or performing a required function. Means are provided for orienting the selector to the received signal. The a-c motor is geared to the main shaft of the typing unit, which in turn, extends motion to the keyboard mechanism. The typing and various functional sections of the typing unit are activated by individual clutches that completely disengage at the termination of each operation cycle and thus reduce the motor load to the minimum during idling.

Paper (single or multi-copy) feeds from a five-inch (maximum) diameter roll mounted on the typing unit, and passes around a platen which rotates but which does not move horizontally. Type pallets are arranged in a small typebox (figure 16-9) which may be detached for cleaning or replacement by another type box. In operation, the type box moves across the paper and presents the proper type pallets to the printing hammer, which drives the pallets and inked ribbon against the paper to print the characters.

In addition to these functions, built-in facilities in the function box permit the addition of selective station call or recognition functions with electrical circuits associated therewith available for remote extension. In such applications, the typing unit may be stripped of all typing and paper feeding mechanisms and utilized for circuit switching or similar applications.



50.113X

Figure 16-7.—Automatic Send-Receive Set (dome opened) AN/UGC-13.

Base/Keyboard

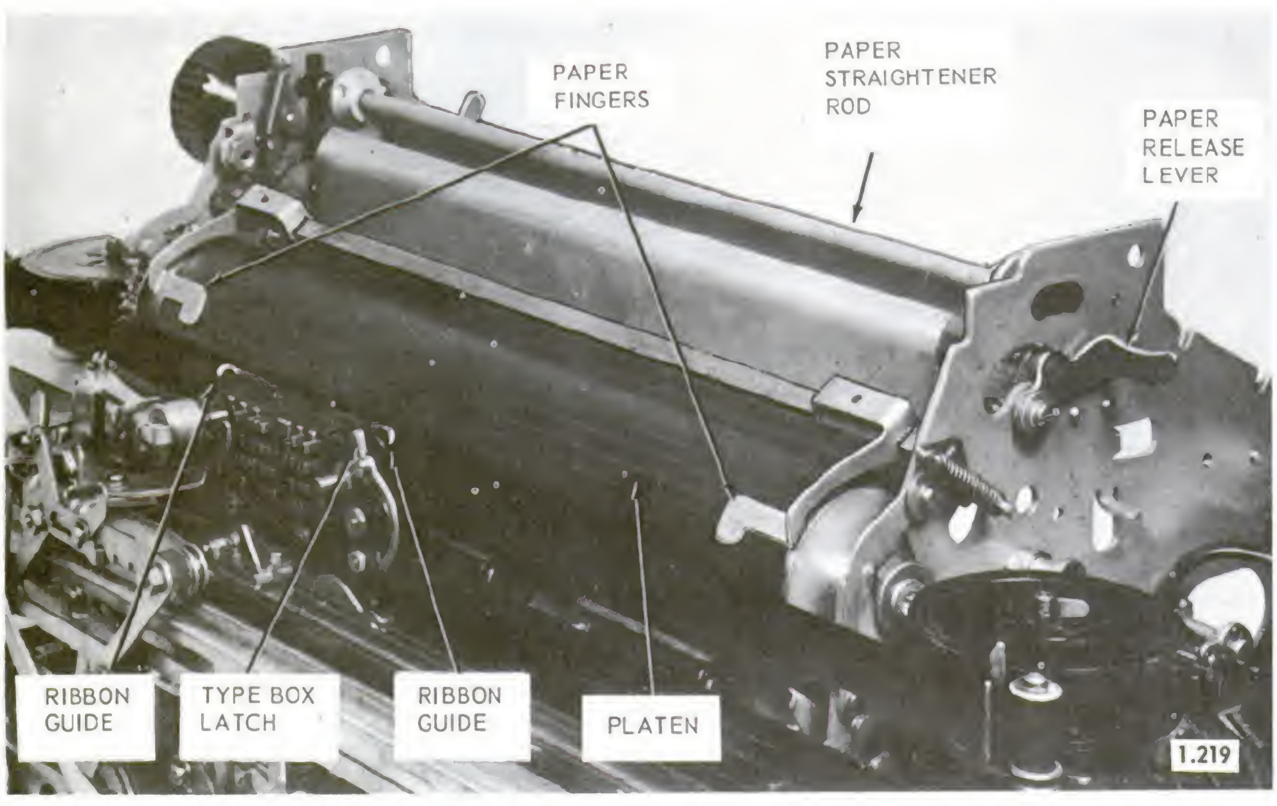
The base or keyboard (figure 16-10A) supports the a-c motor, the typing unit, and in the case of the ASR, the typing reperforator. The keyboard or base is mounted in the cabinet on the rails of a shock mounted cradle. The front of the keyboard or base protrudes beyond the cabinet and is fitted with a rubber gasket that seals the edges of the aperture for silencing effect.

The keyboard for the ASR incorporates code selecting and signal generating mechanisms with synchronous pulsed transmission. Signal line and power line circuits are included. The keys (figure 16-10B) are positioned in the

conventional three bank arrangement with numerals, punctuation marks and special symbols available in upper case positions. Special keys are located directly above the standard keys. The special keys are for local line feed, carriage return, receive, send, and repeat operations. In addition, it has all the necessary elements for the mechanical printing and perforating of tape. The base supports a tape container, a character counter used in connection with the typing reperforator, flexible connections by which rotary motion is imparted to the typing reperforator and transmitter distributor, and a three-position selector switch for determining the mode of operation of the equipment.

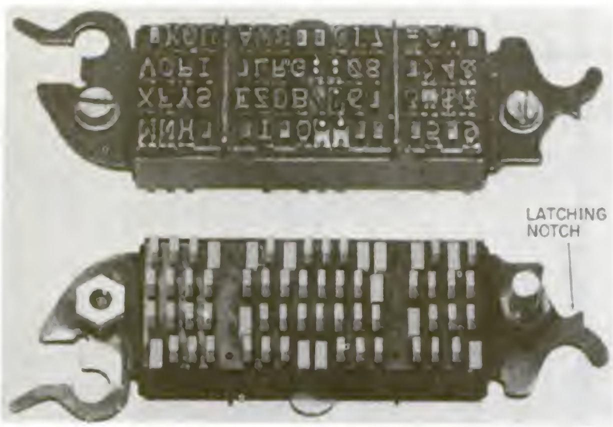
Reperforators

Tape reperforation is accomplished by typing reperforators. Typing Reperforators and Auxiliary Typing Reperforators are part of the Automatic Send-Receive Set. The typing reperforator is mounted on its base/keyboard and can be controlled by its mechanical linkages on the keyboard or, as in the case of the auxiliary typing reperforator, it can be controlled by the signalling code combinations received from the sending station. The product of the reperforations is identical: a transmissible, five-level, fully perforated tape with printed characters corresponding to the perforated code. The reperforators are similar in appearance, design, and operation with identical subassemblies for the typing and perforating mechanisms. The typing reperforator, mounted on the left front corner of the keyboard, is powered through shafts with flexible couplings by the ac motor which is mounted on the right rear corner of the keyboard. The auxiliary typing reperforator, is powered by a separate driving motor. This reperforator and motor are mounted on a special base located above the transmitter distributor base



1.364

Figure 16-8.—Typing unit.



31.28
Figure 16-9.—Type box, front and back.

at the left of the cabinet. It has a power switch, a power line fuse, low tape switch, and a Non-interfering letters tape feedout mechanism.

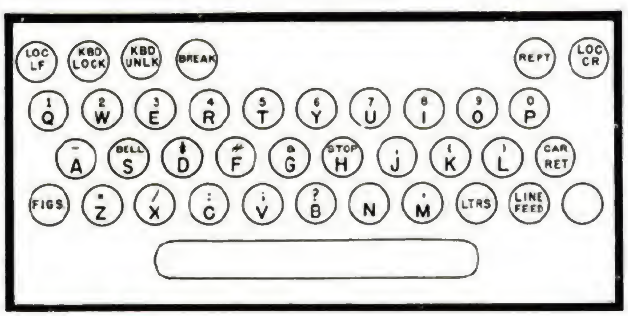
The keyboard typing reperforator (figure 16-11) is mounted on and operated through the ASR teletypewriter keyboard. The keyboard typing reperforator records messages on paper tape as printed characters and combinations of fully perforated code holes. The messages are received from the keyboard in the form of mechanical arrangements which are set up by operation of the keys and are translated by the reperforator into the necessary mechanical motions to type and perforate the information. With the keyboard selector switch in the K (keyboard) position, the selector switch connects the selector magnet on the keyboard typing reperforator into the signal line circuit of the keyboard signal generator, at the cabinet terminal board, to permit preparation of perforated and typed tape simultaneously with signal line transmission. In T (tape) position, the selector switch mechanically engages linkages between the keyboard and the keyboard typing reperforator resulting in manual typing reperforator operation independent of the signal line. A jack shaft directly under the typing reperforator main shaft, flexibly coupled to the keyboard bearing bracket mechanism, transmits power required to operate both perforating and typing mechanisms. A function cam-clutch mechanism keyed to the main shaft and geared to the jack shaft has three cams, two for operation of the rocker bail in K-T and T positions, and the third for resetting the keyboard in T position only. The characters used in printing are embossed on a typewheel which may be replaced to obtain different type faces and character arrangements. Controlled by mechanical arrangements in the keyboard, axial and rotary positioning mechanisms in conjunction with a correcting mechanism select the proper characters by moving the typewheel. A printing mechanism utilizes a hammer to drive the tape and inked ribbon against the typewheel and imprint the selected characters. The ribbon is advanced by a ribbon-feed mechanism. A perforating mechanism steps the tape, rolls in feed holes, and perforates code holes corresponding to the code permutations established in the keyboard. Printing and perforating occur simultaneously, but the characters are printed six spaces to the right of the corresponding code combinations. The typewheel is retracted at the end of each operation so that the last printed character is visible. In addition to the above features, the reperforator is also equipped with a selector assembly. Messages can be received from the channel in the form of signaling code combinations which are translated into mechanical arrangements to control printing and perforation of tape when the control of the ASR keyboard is in K position. This feature of the unit operates from the signal line in essentailly the same manner as the auxiliary unit.

Transmitter Distributor

The transmitter distributor (figure 16-12) mounted on its own base in front of the ASR cabinet dome and to the left, is a mechanical tape reader designed to convert coded messages stored on standard five-level perforated tapes to signalling code combinations for transmission in a telegraph channel. A main shaft powered by flexible shaft connections from the a-c motor on the keyboard through an intermediate gear and shaft on the transmitter distributor base, operates a cam-clutch assembly. The cam-clutch, through a main bail, drives a transfer and signal generating mechanism and a tape feed wheel. The clutch is released by a clutch trip magnet. The unit includes a start-stop switch in which are incorporated tight-tape, shut-off, and free-wheeling tape feed features. A second switch shuts off the equipment automatically when tape runs out. Electrical requirements of the transmitter distributor are supplied by way of the terminal blocks in the

50.92X

Figure 16-10A.—Keyboard and typing reperforator.



31.26

Figure 16-10B.—Model 28 keyboard.

ASR cabinet through a connector on the transmitter distributor base. Transmission speed can be at 45.5 or 75 baud depending upon the gear ratios used.

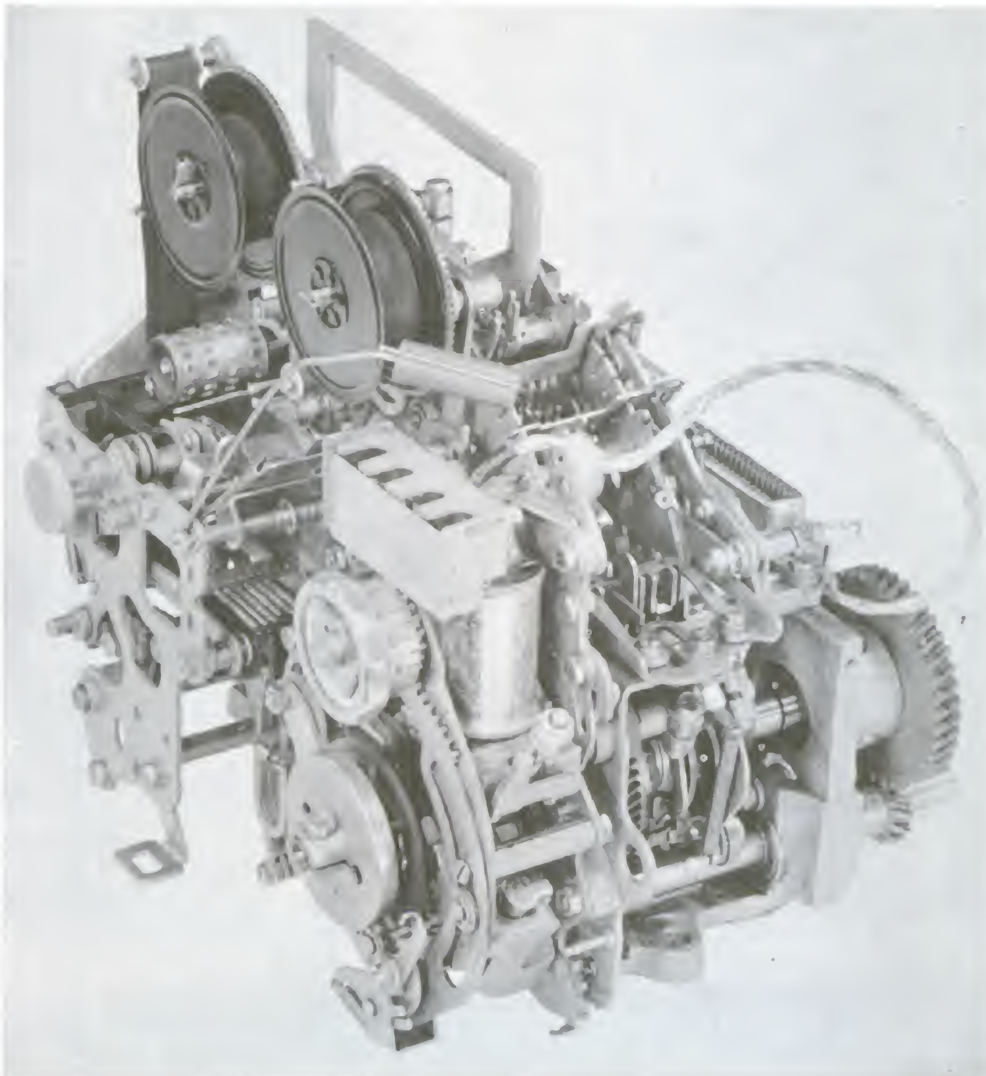
The Transmitter Distributor Base provides mounting facilities for the transmitter distributor. It is a casting mounted on rubber silencing bushings on the left side of the cradle in the ASR cabinet. An intermediate gear assembly connected by flexible shaft couplings to the keyboard mounted a-c motor is located on the rear of the base. An electrical connector and cable are assembled on the right side of the base. A ground strap is provided for connection between the LCXB Base and the cradle of the cabinet, since the base is electrically isolated from the cradle by the rubber silencing bushing. The transmitter distributor is mounted at the front of the base, projecting beyond the cabinet dome.

Motors

The motors are self-contained components mounted on the base, keyboard or on the

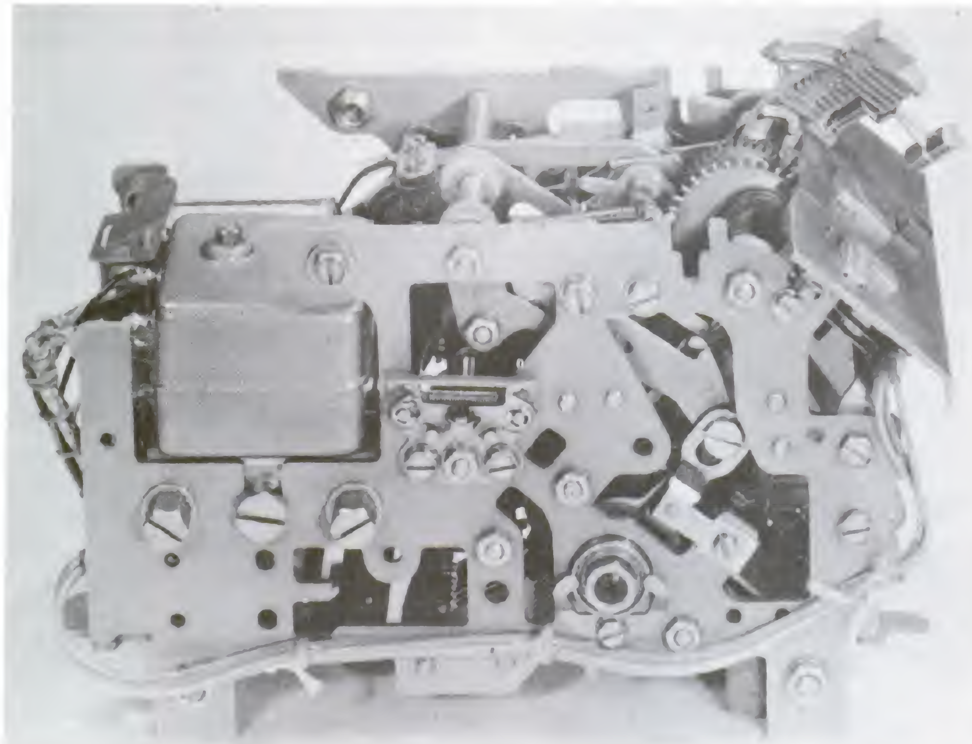
auxiliary typing reperforator base. The LMU3 and 4 motors are used to supply mechanical energy for the auxiliary typing reperforator in the ASR set or for the typing unit in the KSR or RO Sets. The LMU12 and 14 motors are heavy duty motors used to drive the typing unit, keyboard, typing reperforator and transmitter distributor in the ASR Set. Both the light duty and heavy duty motors are furnished for ac synchronous or ac governed operation.

AC SYNCHRONOUS MOTOR LMU3 (Figure 16-13).—This motor is mounted at the rear of the base or keyboard in the RO and KSR Sets and under the auxiliary typing reperforator base in the ASR Set. It supplies rotary mechanical motion to the main shaft of the typing unit or to the main shaft of the auxiliary typing reperforator through intermediate gears. The unit is a 1/20 hp, 115 volt, 60 cycle ac, single phase, capacitor start synchronous motor which runs at 3600 rpm. The motor has a two pole wound stator and a squirrel cage type rotor which is mounted on ball bearings. The stator has a starting winding and a running winding. The starting capacitor and relay and a thermal



50.98X

Figure 16-11.—Typing reperforator.



50.104X

Figure 16-12.—Transmitter distributor (top plate and cover plate removed).

cutout switch are mounted in a compartment under the motor. The motor is supported by a cradle to which it is held by straps at each end. Resilient mounts on the hubs of the motor end bells reduce transmission of vibration. A combination handwheel and fan is mounted on one end of the motor shaft. The motor shaft turns in a counterclockwise direction as viewed from the fan end.

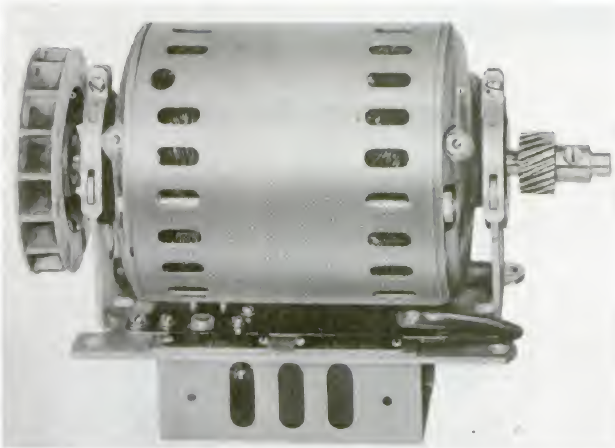
AC GOVERNED MOTOR LMU4 (Figure 16-14).—The LMU4 governed motor is similar to the synchronous motor in location, mounting function. The unit is a 1/20 hp, 115 volt, 50-60 cycle ac governed motor which runs at a governed 3600 rpm. A combined governor and fan are mounted on a motor shaft, which is supported on ball bearings. An electromechanical governor is wired in series with the armature and two field windings. Targets for speed checking are marked on the governor cover. The entire motor is shielded to minimize radio interference. A shielded compartment on the underside of the motor houses the governor resistor and capacitor, as well as an electrical noise suppressor across the power leads.

AC SYNCHRONOUS MOTOR LMU12.—This is a heavy duty motor used to supply rotary motion to the main shafts of the typing unit, keyboard, typing reperforator and transmitter distributor in the ASR Set. It is a 1/12 hp, 115 volt, 60 cycle ac, single phase, capacitor start synchronous motor which runs at 3600 rpm. It is identical in appearance and mounting requirements to the LMU3 motor.

AC GOVERNED MOTOR LMU14.—This unit is a 1/15 hp, 115 volt, 50-60 cycle ac governed motor which runs at 3600 rpm. It is identical in appearance and mounting requirements to the LMU4 motor. Since it is a heavy duty motor its application is the same as the LMU12.

Electrical Service Assemblies

The electrical service assemblies are units that incorporate the motor switch, fuse,



50.108X
Figure 16-13.—AC synchronous motor.

transformer, rectifier, electronic keyer and other elements which are associated with the power and signal line circuits. These units interconnect with other components of the Teletypewriter Set by way of the terminal blocks located in the cabinet of the set.

The Electrical Service Assembly used with the rack-mounted Receive-Only (RO) or Send-Receive (KSR) set is housed in a rectangular container for rack mounting and is painted the same color as the cabinet. It mounts a power switch, fuse holders, and monitor jacks on the front and contains a transformer, rectifier, and electronic keyer assembly. The keyer assembly function is to repeat polar line signals in a neutral local loop to the selector coils of the typing unit. Power factor correction capacitors, when required, are also mounted in this container.

The Electrical Service Assembly used with the console mounted Send-Receive (KSR) or Automatic Send-Receive (ASR) Set consists of a rectangular sheet metal box, with a leg at each of the four corners. It is mounted in the cabinet behind the keyboard with the open side down. The legs serve as supports when the unit is inverted for servicing. It contains the main power line switch, which is operated remotelv by mechanical linkage from the front of the cabinet, fuse holders, appropriate transformer, a rectifier and one or three electronic keyers, depending upon the needs of the set. A cable from each end of the electrical service assembly connects to the terminal boards at the rear of the cabinet.

Electronic Keyer

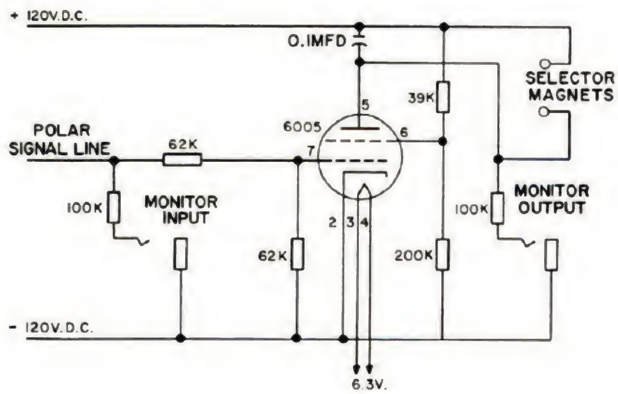
The telegraph signal applied to the selector magnets must be on-off direct current, nominally 0.035 ampere, when the polar signal line is "marking." The electronic keyer (a schematic of which is shown in figure 16-15) in the electrical service assembly repeats the incoming polar line signals in a neutral local loop to the selector coils of the receiving unit. A rectifier in the electrical service assemblies supplies operating current to the local loop. The input telegraph signal to the keyer is a direct current polar signal of 60 volts. Transmission signal line current must be furnished from an external rectifier.

TAPE RELAY TELETYPEWRITER EQUIPMENT GROUPS

REPERFORATOR TRANSMITTER GROUP AN/FGC-51

The teletype Model 28 Reperforator Transmitter Group AN/FGC-51 (figure 16-16) is basically a mechanical relay or storing device for printing telegraph intelligence. The group provides for fully automatic perforation, storage, and retransmission of an entire message on tape, including the last character received.

50.110X
Figure 16-14.—AC governed motor.



1.365
Figure 16-15.—Electronic keyer schematic.

TRANSMITTER GROUP TT-310
OF AN/FGC-59

The Teletype Model 28 Transmitter Group TT-310 (figure 16-17) transmits from perforated tape to the outgoing signal lines at 75.0 baud. This group provides message numbering, wiring and electrical control facilities to operate three multiple mounted Transmitter Distributor Units in parallel with three other multiple mounted transmitter distributor units. Each of the parallel units is automatically switched into the signal line when the primary TD senses the end of tape.

TYPING REPERFORATOR MONITOR
GROUP TT-309 OF AN/FGC-59

The Teletype Model 28 Typing Reperforator Monitor Group (figure 16-18) records the messages in the form of fully perforated tape and characters printed on the tape sent out by the transmitter distributors. The tape from the reperforator is wound by the tape winders from which a full reel of tape can be conveniently removed for storage. The group provides wiring and electrical control facilities to operate two Model 28 Multiple Typing Reperforator Sets and two Model 28 Tape Winder Sets.

TYPING REPERFORATOR RECEIVING
GROUP TT-308 OF AN/FGC-59

The Teletype Model 28 Typing Reperforator Receiving Group (figure 16-19) receives messages from six separate incoming lines in the form of 5 level start-stop signals and converts them into fully perforated tape with characters printed on the tape. The Group provides wiring and electrical control facilities to operate two Model 28 Multiple Typing Reperforator Sets. Slots in the cabinet provide a convenient tearing edge for the tape at the end of the message. Tape holders and tape bins are mounted on the front doors and tape clips are mounted on the top of the cabinet.

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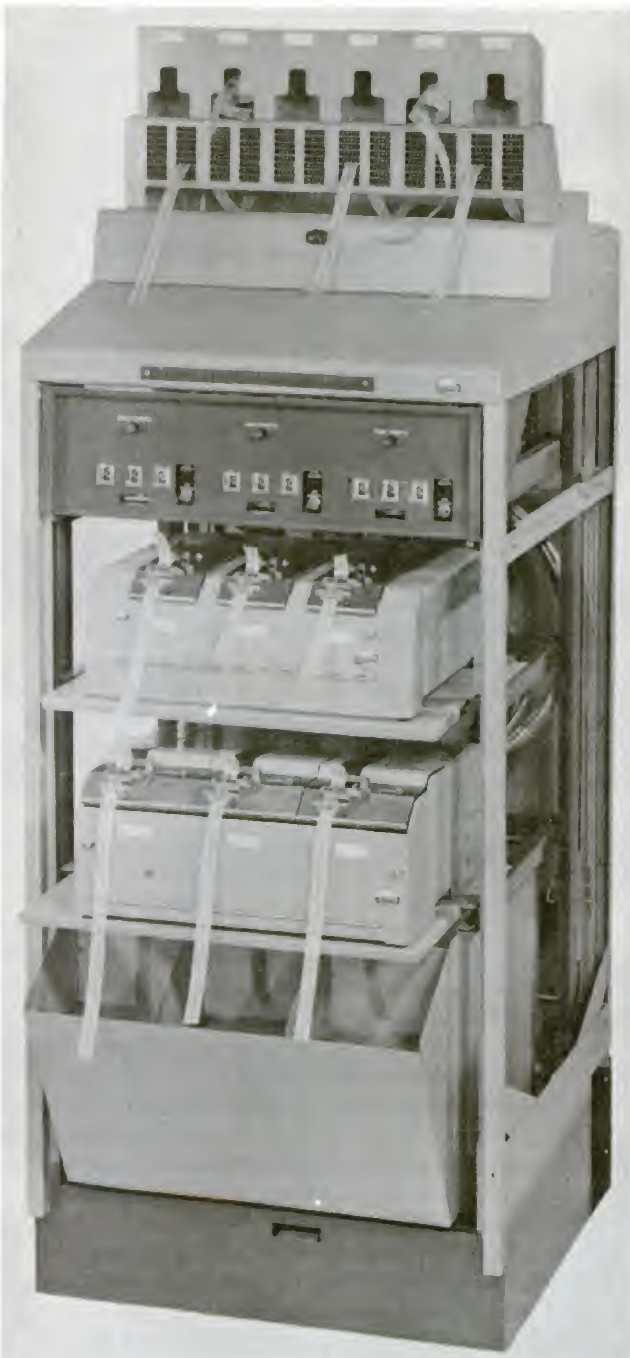
Figure 16-16.—AN/UGC-14 or AN/FGC-51 reperforator transmitter group.



1.367X
Figure 16-17.—TT-310 of AN/FGC-59 transmitter group.

TAPE FACTORY

Although only one copy of a tape message is received, routing instructions often require it to be relayed over several circuits. To avoid the delay of running a single type through several TD's duplicates are made by putting the tape through duplicating reperforators called a tape factory. As many as six copies can be made at one time. If more than six are needed, the process is repeated.

CIRCUIT TYPES

The word "circuit" is used in two senses. First, in the electrical sense: a continuous conductor for the flow of electrons; second, in the communications sense: a path between two or more points, capable of providing one or more channels for the transmission of intelligence. In the discussion of teletypewriter operation we shall concentrate on the communications sense of the word.

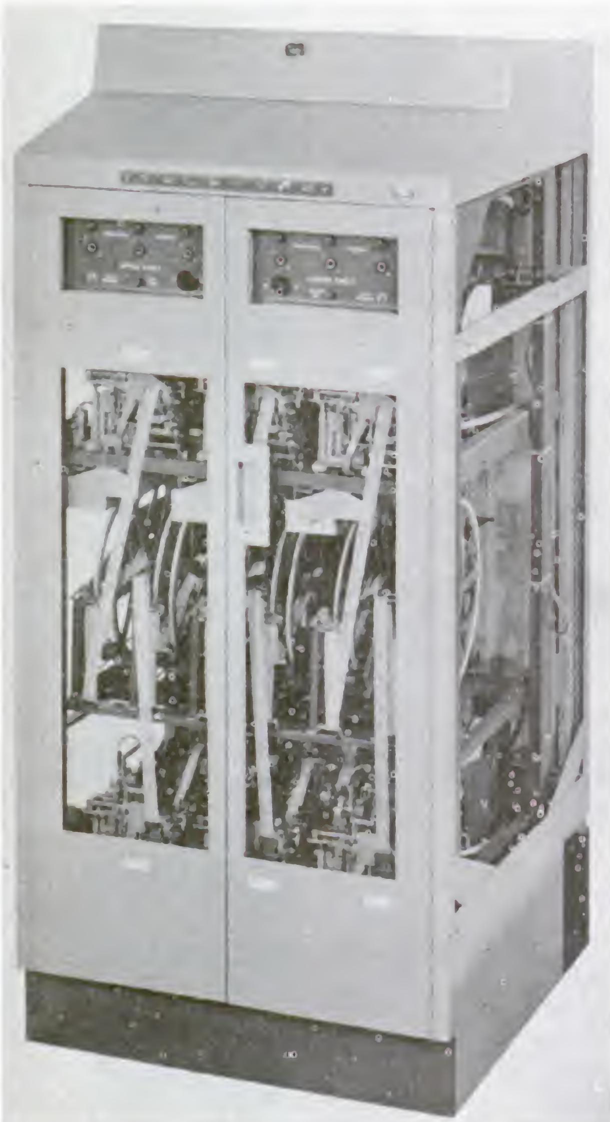
A simplex circuit is a CW, voice, or RATT circuit capable of transmissions in both directions, but not simultaneously. Its landline counterpart is the half-duplex circuit.

A duplex circuit is a radio or landwire circuit capable of carrying transmissions in both directions at the same time.

You have learned that whenever a carrier is amplitude modulated, two sideband frequencies are produced that carry the intelligence present in the audio frequency. Only one sideband is necessary for transmission of the signal, and a transmitter in which the carrier has been suppressed may be used to send a separate message on each of the sidebands. The messages from the two audio channels are made to modulate the same carrier, but modulation takes place in different modulators.

The output of the two modulators contains sidebands formed by heterodyning the individual audio signals with a common carrier suppressed in the output. The filters remove the lower sideband from one modulator output and the upper sideband from the other. Thus, each of the two sidebands conveys a separate message and may be used as a separate channel. At the receiving end, the carrier frequency is reinserted and the intelligence recovered.

As used in the Naval Communications System, six or more teletypewriter channels are transmitted on one sideband of each SSB circuit through a frequency multiplexing system. Frequency multiplexing is a process for including



1.368X
Figure 16-18.--TT-309/UG of AN/FGC-59 typing reperforator monitor group.

multiple sets of transmissions in a single bandwith by crowding, or "stacking" subchannel bandwidths in the assigned transmission bandwidth. There are also systems today that use time division multiplexing to accomplish multichannel transmission. This process interlaces the band groups or the individual bands of several channels and transmits them on a single bandwidth.

To give added range to landline transmissions, repeaters are inserted in the line to renew the strength of weak signals as they pass through the wire. Repeaters are to two kinds. First, there is the "straight" repeater, which strengthens (amplifies) the signal just as it is received. Unfortunately, this type also amplifies any interference the signal may have picked up along the wire.

1.369X
Figure 16-19.—TT-308 of AN/FGC-59 typing reperforator receiving group.

The other repeater is the "regenerative" type. It builds, or regenerates, an entirely new signal from one that is worn out or distorted, and eliminates the interference. Both types of line repeaters retransmit signals automatically, using a local source of power. They may be placed at the end of the line (terminal), or at an intermediate point along the line.

Repeaters cannot be used with RATT transmissions. Radioteletypewriter is further handicapped by the same atmospheric disturbances which sometimes hamper radiotelegraph communications. Although RATT transmits on radio waves instead of wires, the basic equipments are the same as those used in landline teletypewriter operation. The difference is that RATT requires radio transmitters and receivers to send and pick up signals.

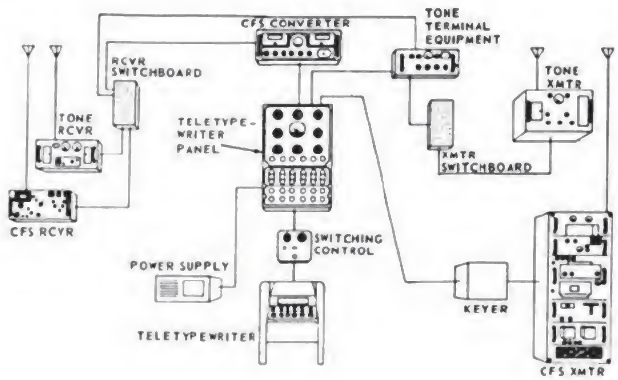
When two teletypewriters are wire-connected, the exchange of intelligence between them is direct. But when the teletypewriters are not joined by wire, operation is more complex. Direct-current mark and space intervals cannot be sent through the air.

The gap between the machines must be bridged by radio. To bridge the gap, a radio transmitter and receiver are needed. The transmitter produces a radio-frequency carrier wave to carry the mark and space intelligence. Also, a device such as a keyer is needed to change the d-c pulses from the teletypewriter into corresponding mark and space modulation for the carrier wave in the transmitter. The radio receiver and a converter are required to change the radio-frequency signal back to d-c pulses.

RATT SYSTEMS

The Navy uses two RATT systems. One, the tone-modulated system, is similar to the familiar AM radio. The other, the carrier-frequency shift system is similar to the standard FM radio. The two systems are shown integrated in figure 16-20. The differences in the Navy's two RATT systems, as well as their names, are derived from the nature of the carrier wave used. The tone-modulated carrier wave is for short-range work, and the carrier-frequency shift system is for long-range work.

Figure 16-21 shows a modulated carrier wave with audio tone impulses impressed on the radio-frequency carrier wave, with corresponding d-c mark and space signals.



1.225

Figure 16-20.—Basic RATT transmit-receive system.

Figure 16-22 shows a carrier-frequency shift wave which increases and decreases to denote mark and space d-c impulses.

In the operations shown in figures 16-21 and 16-22 the d-c teletypewriter signal that can travel only by wire becomes, through the medium of a tone terminal or keyer unit, either a tone-modulated signal or a carrier-frequency shift signal for radio carrier wave transmission.

Short-Range System

To transmit messages by the short-range system, a page printer, a tone terminal, and a transmitter are used. The printer sends out a d-c signal. The signal is changed to audio tones in the tone terminal. The transmitter impresses the audio tones on the carrier and sends out a tone-modulated carrier wave (figure 16-23).

To receive messages with the short-range system, a radio receiver, a tone converter, and a page printer are required. The tone-modulated carrier wave enters the receiver, which extracts the signal intelligence and sends the audio tones into d-c mark and space pulses for the page printer (figure 16-24).

In practice the same tone terminal is used for the receiving and the sending circuits since it contains both a transmit "keyer" unit and a receiver "converter" unit.

Long-Range System

At the transmitting end of the long-range system are a page printer, a transmitter, and a

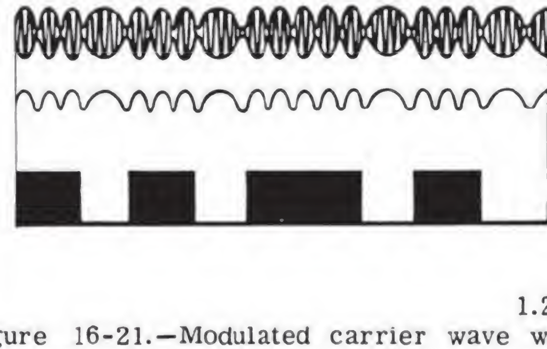
frequency shift keyer unit. The keyer unit is built into the newer transmitters, but in some older systems it is a separate piece of equipment. When the page printer is operated, the d-c mark and space signals are changed by the keyer unit into frequency shift intervals. The frequency shift intervals are transmitted as carrier-frequency shift signals (figure 16-25).

On the receiving side of the long-range system are a receiver, a frequency shift converter, and a page printer. When the carrier-frequency shift signal enters the receiver, it is detected and changed into a corresponding frequency-shifted audio signal. The audio output of the receiver is fed to the converter, which changes the frequency-shifted audio signal into d-c mark and space signals (figure 16-26).

When the carrier-frequency shift system is combined with the tone-modulated system, several more pieces of equipment are needed—a teletypewriter panel, a power supply, a switching control, a transmitter switchboard, and a receiver switchboard.

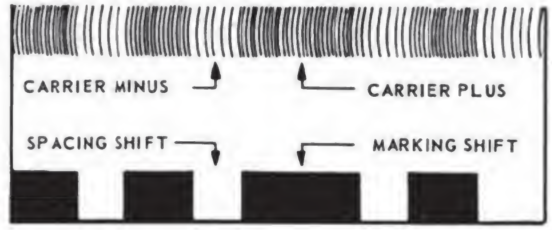
The teletypewriter panel is capable of handling six channels, or loops. The power supply furnishes the direct "looping" current for all teletypewriter d-c signals. The switching control, located at the page printer, is used to select the system desired. The transmitter switchboard and the receiver switchboard are used to integrate the RATT systems with other communication systems on board ship. Integration of the various systems results in a compact and flexible installation.

The teletypewriter panel interconnects the page printer with all the different radio keyers and converters as shown in figure 16-20. The teletypewriter panel controls the direct looping



1.226

Figure 16-21.—Modulated carrier wave with corresponding audio electrical impulses with mark and space signals.



1.227

Figure 16-22.—Frequency of the carrier wave increases and decreases corresponding to mark and space signals.

current channels. Figure 16-27 is a diagram of one teletypewriter loop.

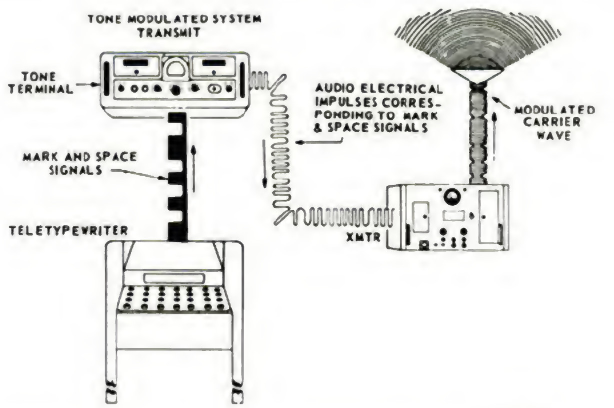
When the teletypewriter system is in operation, the electron current—which flows from negative to positive—flows from the negative side of the power supply through the teletypewriter panel, through the page printer, back through the teletypewriter panel, into a converter or keyer unit, through the teletypewriter panel a third time, and from there to the positive side of the power supply.

When the d-c loop is alternately opened and closed by the page printer or one of the converters, the result is current and no-current or mark and space intervals that characterize the d-c teletypewriter signal. This is what happens in all of the d-c loops in both of the Navy's RATT systems.

The looping current is controlled by a rheostat in the teletypewriter panel. A common power supply is used for all teletypewriter panels in shipboard installations. In the front panel of the cabinet each of the six channels, or circuits, has a pair of looping jacks, a set jack, and an additional jack for miscellaneous teletypewriter requirements.

The numerous terminal and patching connections in the teletypewriter panel provide many different circuit possibilities. For instance, a keyer or converter circuit that terminates in channel 2 can be patched across to channel 5 to connect with teletypewriter equipment that ends there. A dummy plug is used to short out the unwanted portion of the circuit,

In both the tone-modulated system and the carrier-frequency shift system, all teletypewriter signals pass through the teletypewriter panel that controls the looping current in all the circuits. The teletypewriter panel integrates



1.228
Figure 16-23.—DC mark and space signals converted to audio tones and impressed on carrier waves.

the tone-modulated and the carrier-frequency shift systems. It provides every possible RATT interconnection available on board ship. This operational flexibility gives maximum efficiency with the fewest circuits and the least amount of equipmext in the Navy's compact RATT systems.

RATT RECEPTION

The basic components for converting an r-f frequency-shift signal into a signal for controlling the d-c loop of a teletype printer are illustrated in the top row of the simplified block diagram of a frequency-shift converter in figure 16-28.

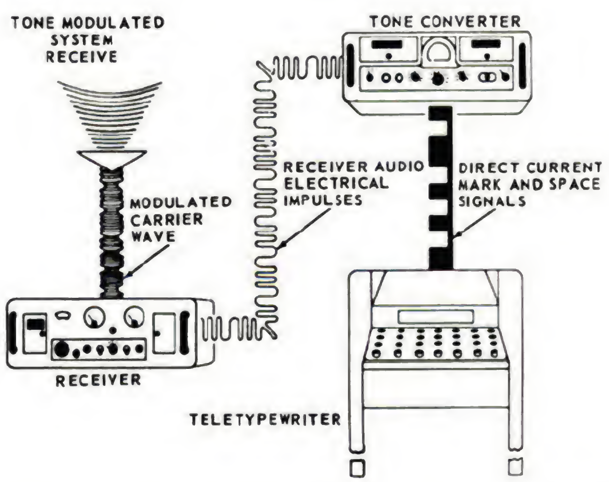


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Figure 16-24.—Operation of the tone converter.

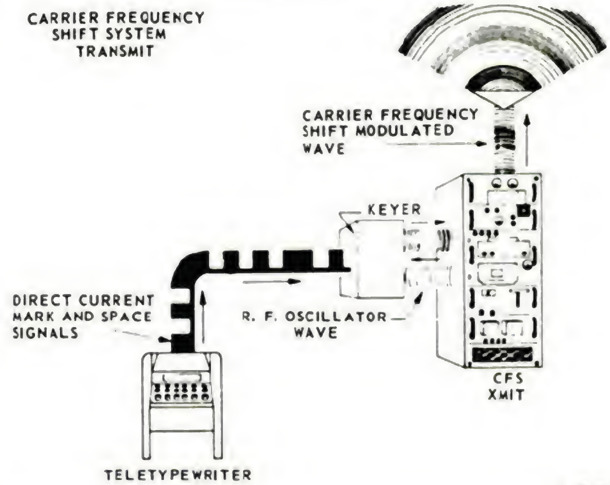

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Figure 16-25.—DC mark and space signals are changed by the keyer unit into frequency shift intervals (nominal carrier plus or minus).

The frequency shift of the r-f signal is converted in the radio receiver at the second detector (by the heterodyne action of the BFO) into either a high audio tone (mark) or a low audio tone (space). These signals are converted in the a-f discriminator into d-c pulses. The d-c pulses are fed into a keyer and electronic-relay circuit, which opens and closes a d-c loop circuit of an associated teletype printer, causing the mark-space characters to operate the teletype printer.

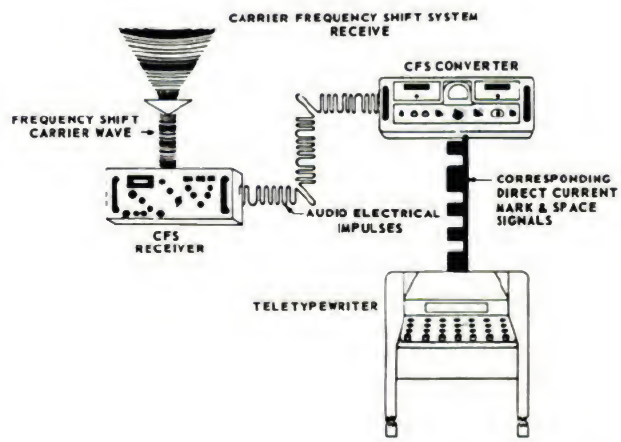

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Figure 16-26.—Conversion of frequency-shifted carrier wave into mark and space signals.

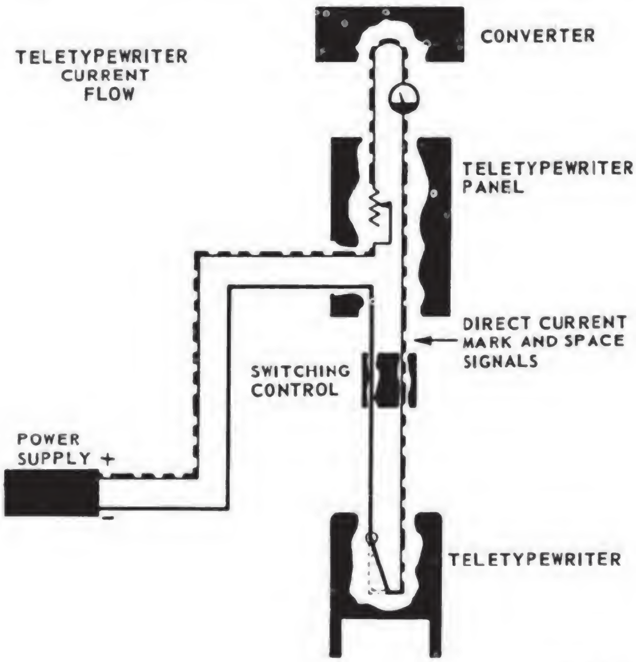

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Figure 16-27.–One complete loop, with the electron flow from the negative to the positive side of the power supply.

The lower blocks in figure 16-28 represent the circuits for a keyer-tone output. This output is used to operate remotely located telegraph or teletype terminal equipment over wire lines or radio links. A tone generated by the audio oscillator is fed to the tone modulator. The bias of this unit is controlled from the keyer and electronic relay. For space signals, the pushpull output stage is biased beyond cutoff so that the audio tone is blocked from the output. For mark signals from the keyer the bias is decreased to that of a normal pushpull amplifier so that the audio tone is amplified in the tone modulator and delivered to the output circuit.

The frequency versus mark-space relations shown in figure 16-28 are for typical operation. For this case the higher radio frequency represents a mark and the lower represents a space. However, the opposite arrangement is sometimes used in which the lower radio frequency represents a mark and the higher represents a space. A reversing switch (not shown) following the discriminator provides a means of changing the polarities of the d-c output voltages so that the higher frequency will produce a negative voltage (space signal) and the lower frequency will produce a positive voltage (mark signal). The radio receiver is tuned to the desired signal, and the output and frequency vernier (BFO) controls are adjusted for the desired output to the converter.

DIVERSITY RECEPTION

Because of fading and interference over long distances, diversity reception is employed, In space diversity two receivers are tuned to the same frequency but the receiving antennas are spaced more than one wavelength apart. In frequency diversity the two receivers are tuned to separate frequency-shift carriers (of different frequencies), which are simultaneously carrying the same mark-space characters. The output of each receiver is connected to its associated frequency-shift converter, which converts the frequency shift characters into d-c pulses. These mark-space pulses are fed to the comparator where an automatic circuit selects and uses the better of the two signals to ultimately control an automatic teletype printer and to produce a keyed output tone for remote telegraph or teletype operation, as previously described.

Converter-Comparator Group

The Frequency-Shift Converter-Comparator Group AN/URA-8B comprises two Frequency-Shift Converters, CV-89A/URA-8A, and one Comparator, CM-22A/URA-8A, as illustrated in figure 16-29. In diversity reception the audio outputs of two standard Navy receivers are fed to their associated frequency-shift converters, as shown in the block diagram in figure 16-30. The d-c signals from the discriminator circuits of the two frequency-shift converters are compared in the mark-space selector that automatically selects the better mark and the better space pulse for each character. The second frequency-shift converter is identical to the first and is represented by a single block for simplicity. The receivers may be operating on space diversity (if shore based) or frequency diversity (if aboard ship) on any radio frequency within their ranges. The frequency-shift converter is described first. The comparator is then described briefly and common operating adjustments are emphasized last.

FREQUENCY SHIFT CONVERTER.—Two Frequency-Shift Converters, Navy Model

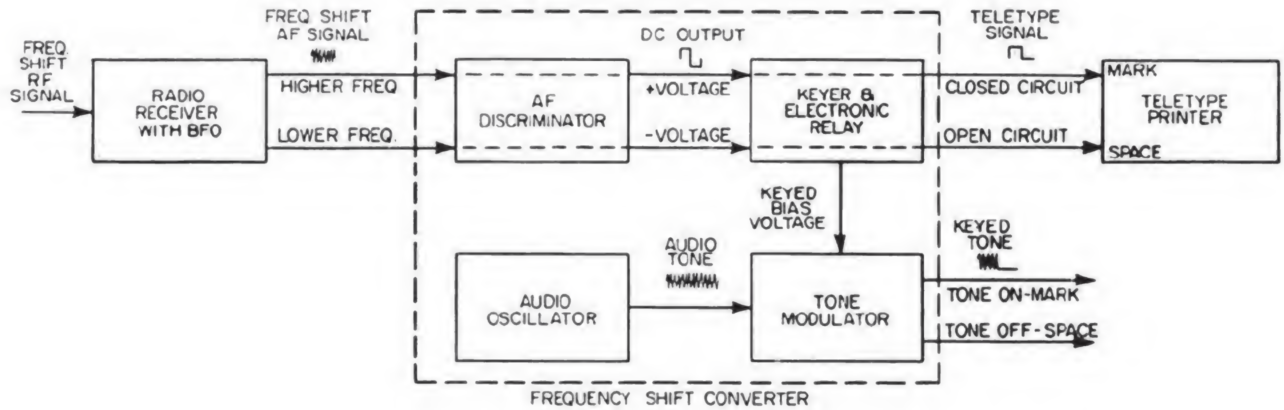

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Figure 16-28.—Simplified block diagram of a frequency shift converter.

CV-89A/URA-8A, are used in the Converter-Comparator Group AN/URA-8B. Each frequency-shift converter is made up of; (1) discriminator subunit, (2) oscillator-keyer subunit, (3) monitor subunit, (4) power-supply subunit, (5) cable-filter assembly, (6) blower subunit, and (7) chassis-panel assembly.

The discriminator subunit contains wide-shift (200 to 1000 cycles) and narrow-shift (10 to 200 cycles) filters, a discriminator circuit, slow-speed (60 words per minute or less) and fast-speed (more than 60 words per minute) filters, and an axis (bias) restorer circuit. The discriminator converts frequency shifts into corresponding voltages, as illustrated in figure 16-31.

The filters attenuate spurious signals above the frequency of the pulse-rate circuit to prevent faulty operation due to noise, harmonics, and so forth.

The axis restorer maintains the optimum axis, or bias, for keying nonsymmetrical signals. It produces an optimum output signal when the received signal is weighted heavily on one side or the other, either mark or space. It will lock up (close the loop circuit) the teletype circuit when a prolonged mark or space signal condition develops. The setting of the threshold control affects the time required to lock up the teletype loop circuit.

The oscillator-keyer subunit contains the circuits for keying the teletype d-c loop and operating the teletype printers. It also provides a keyed-tone output by keying a self-generated tone, which may be selected as any one of eight audio frequencies. Provision is made for the use of an external tone, if desired.

This circuit is used in single receiver operation; but in diversity reception the signal from the converter is taken directly from the lowpass filter (after the discriminator) and fed to the comparator without using the tone and output circuits of the oscillator-keyer subunit. These are available, however, if it is desired to use the signal from one channel of the system while operating in diversity reception.

The monitor subunit includes a 2-inch cathode-ray oscilloscope used as a monitor for indicating proper tuning of the receiver, for checking the approximate width of the frequency shift of the signal, and for observing the polarity of the mark-space characters and other details of the signal. It employs a 60-cycle, sine-wave sweep. The vertical amplifier gain control is calibrated in cycles of shift, which are represented by a full pattern between horizontal lines marked on the screen window. The customary oscilloscope controls are provided. An external connection is provided for using a remote monitor or test oscilloscope.

The power supply subunit furnishes all the power required by the other subunits of the frequency-shift converter and is designed to operate from a power source of 105/115/125 volts, 50 to 60 cycles, single phase. A link connector is provided for selecting the correct transformer tap for the particular voltage being used.

The cable filter assembly carries all the connections to the circuits of the chassis-panel assembly and its subunits. On the rear of the

cable-filter assembly are ten connectors; one for blower power, and nine extending (in a row) out through the back of the case for accommodating all input and output connections to the frequency-shift converter.

The cable filter assembly removes extraneous noise and other signals, which might cause errors in keying. It includes r-f filters for the a-c input, the teletype output, the tone output, and the external tone input circuits.

The blower subunit is mounted on the rear of the case. It forces air through the unit for ventilation when the equipment is being used in high-temperature spaces. The motor operates on 110 volts, 60 cycles, and receives its power by way of a connector on the cable filter assembly. The air intake opening of the cast aluminum housing is covered by an air cleaner, which has an aluminum cloth filter pad. Just inside this opening is a thermostatic switch, which automatically closes to start the motor when the temperature exceeds approximately 49° C.

The chassis-panel assembly consists principally of the front panel and a skeleton chassis into which the four previously described subunits are plugged and mounted. It has cabled wiring carrying the circuits between the receptacles for the subunits and cable filter assembly and to the electrical components on the front cable. The front panel components include the a-c power switch, the pilot light, and two monitor jacks. Other controls and indicators are described under "operation."

COMPARATOR.—The Comparator CM-22A/URA-8A includes (1) a selector subunit, (2) a power-supply subunit, (3) a cable-filter assembly, (4) a blower subunit, (5) a chassis-panel assembly, and (6) a case.

The selector subunit contains the circuit that compares the simultaneous signals for the two frequency-shift converter units and selects the best mark pulse and best space pulse for each character in the signals. The portion of the selector subunit in which this action occurs is illustrated in figure 16-32.

For example, assume that the first converter delivers a 3-volt positive pulse with respect to

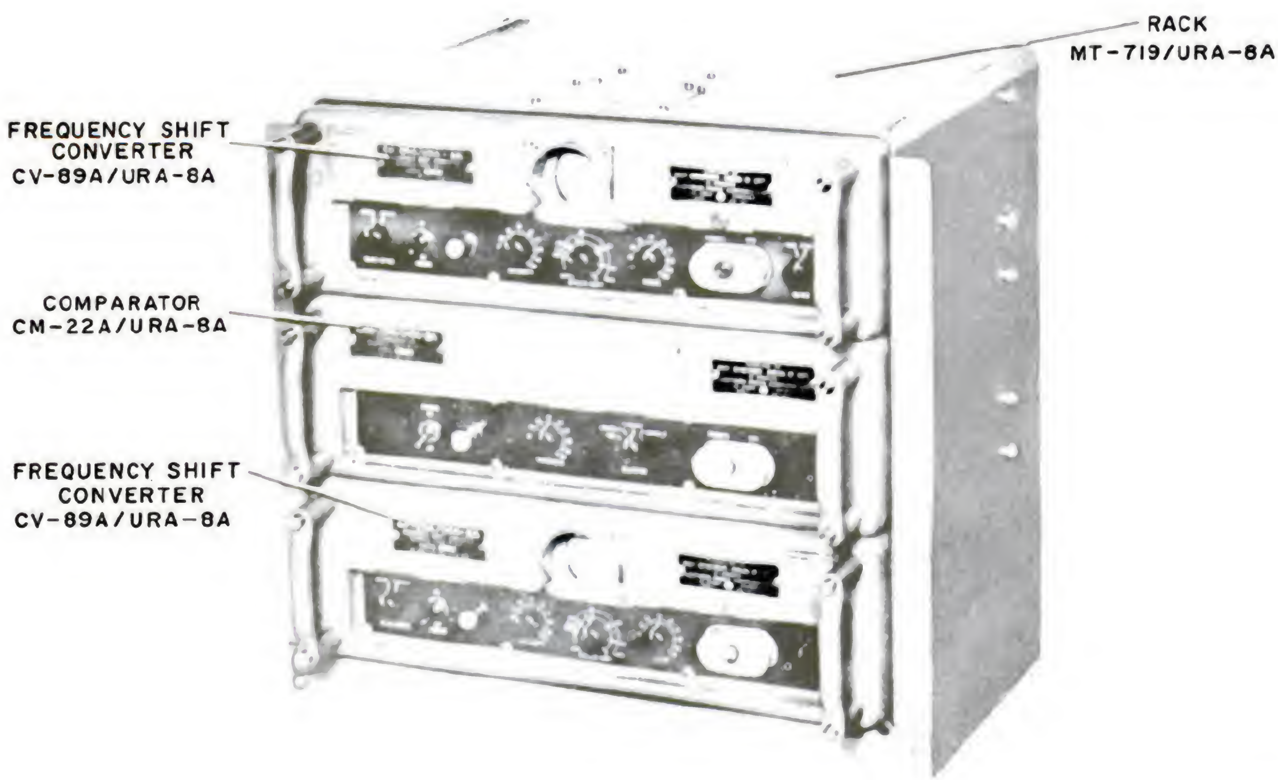

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Figure 16-29.—Frequency-Shift Converter-Comparator Group AN/URA-8B.

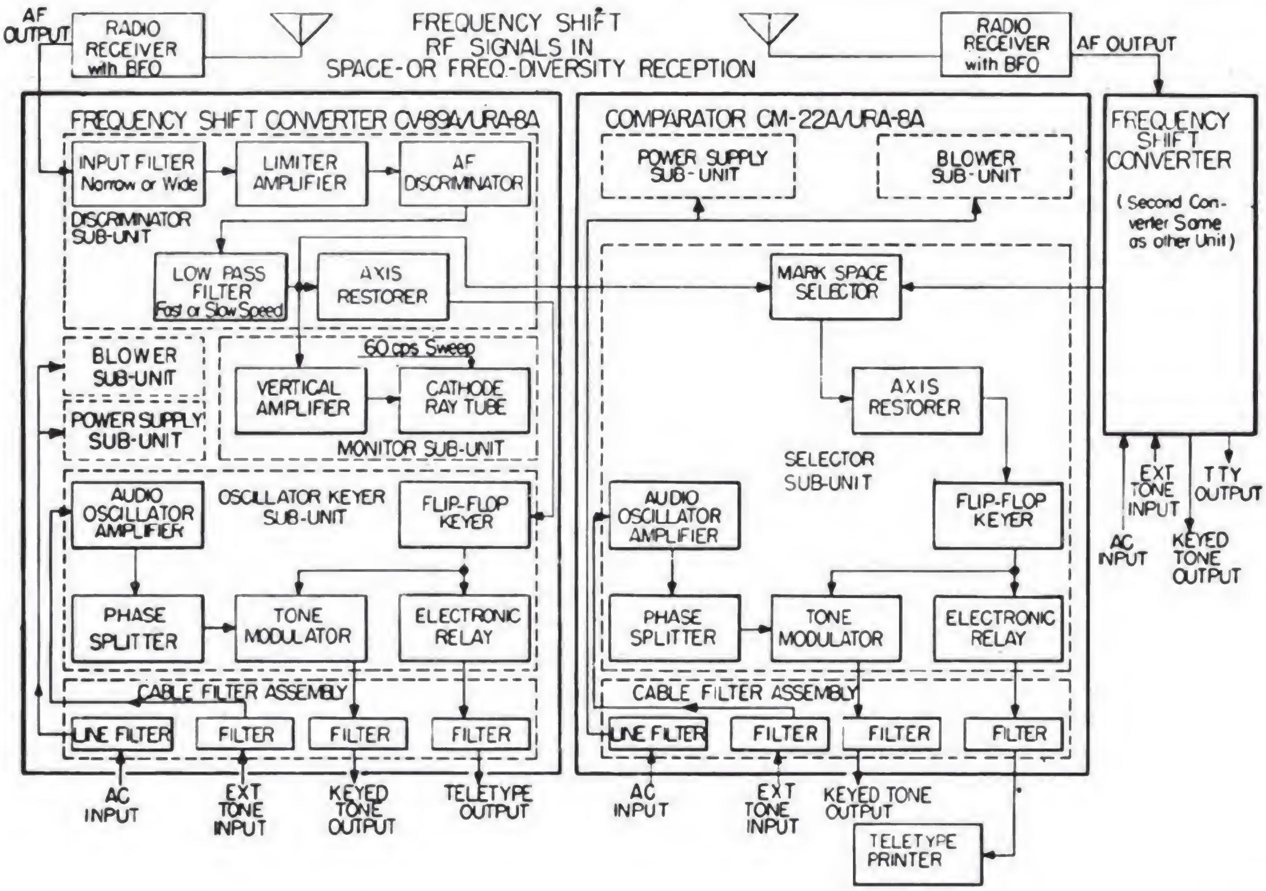

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Figure 16-30.—Block diagram of Frequency-Shift Converter-Comparator Group AN/URA-8B.

ground at the same time that the second converter delivers a 2-volt positive pulse. The 3-volt positive pulse will pass through V1A with negligible drop and develop 3 volts across R1. (Assume that the lower end of R1 is at or near ground potential.) This action makes the cathode of V2A 3 volts positive to ground; but the signal from the second converter is only 2 volts positive to ground. Hence V2A is cut off (its plate is negative with respect to its cathode), and only the diode with its plate positive with respect to its cathode will pass the signal. Thus in this example the signal from the first converter is selected by the comparator. The same selection occurs for the negative pulses at V1B and V2B; these pulses have R2 as their common load resistor.

When the signals from the two comparators have equal magnitudes, there is some combining due to phase difference, but otherwise the circuits pass only the stronger mark (positive) or the stronger space (negative) pulse. The selection is instantaneous even to the selection of parts of poorly shaped pulses.

Following the mark-space selector is an axis restorer similar to that in the frequency-shift converter, after which the keying, tone, and output circuits are identical to those in the frequency-shift converter. The selected mark-space pulses are used by these circuits to key the teletype d-c loop and produce the keyed tone output.

The power supply unit supplies the power required to operate the selector subunit and, like the power supply in the frequency-shift converter, is designed with a link for adjusting the transformer to operate form 105/115/125 volts, 50 to 60 cycles, single phase.

The cable filter assembly of the comparator is nearly identical to the corresponding

assembly of the frequency-shift converter. The individual filters in the comparator cable filter assembly are duplicates of those in the frequency-shift converter, filtering the a-c input, the teletype and tone outputs, and the external tone input circuits.

The blower subunit on the rear of the comparator is identical to the one on the frequency-shift converter.

The chassis-panel assembly of the comparator consists principally of the front panel and a skeleton chassis into which the two subunits are plugged and mounted. Its general construction is similar to that of the frequency-shift converter chassis-panel assembly. Cabled wires carry the comparator circuits in the chassis panel assembly between the subunit and cable-filter receptacles and to the electrical components on the front panel. The front panel components include the a-c power switch, the pilot light, and two monitor jacks. Other controls are described under "operation."

OPERATION.—The operating controls of Frequency-Shift Converter CV-89A/URA-8A are illustrated in figure 16-33A, and those for Comparator CM-22A/URA-8A are illustrated in figure 16-33B. The associated monitor oscilloscope patterns are illustrated in figure 16-33C.

In order to obtain optimum performance of the converter-comparator group, it is necessary for the CT M to have a basic understanding of the receivers that are used with this equipment. The specific technical manual for the radio receivers being used should be available to the CT M to provide complete instructions.

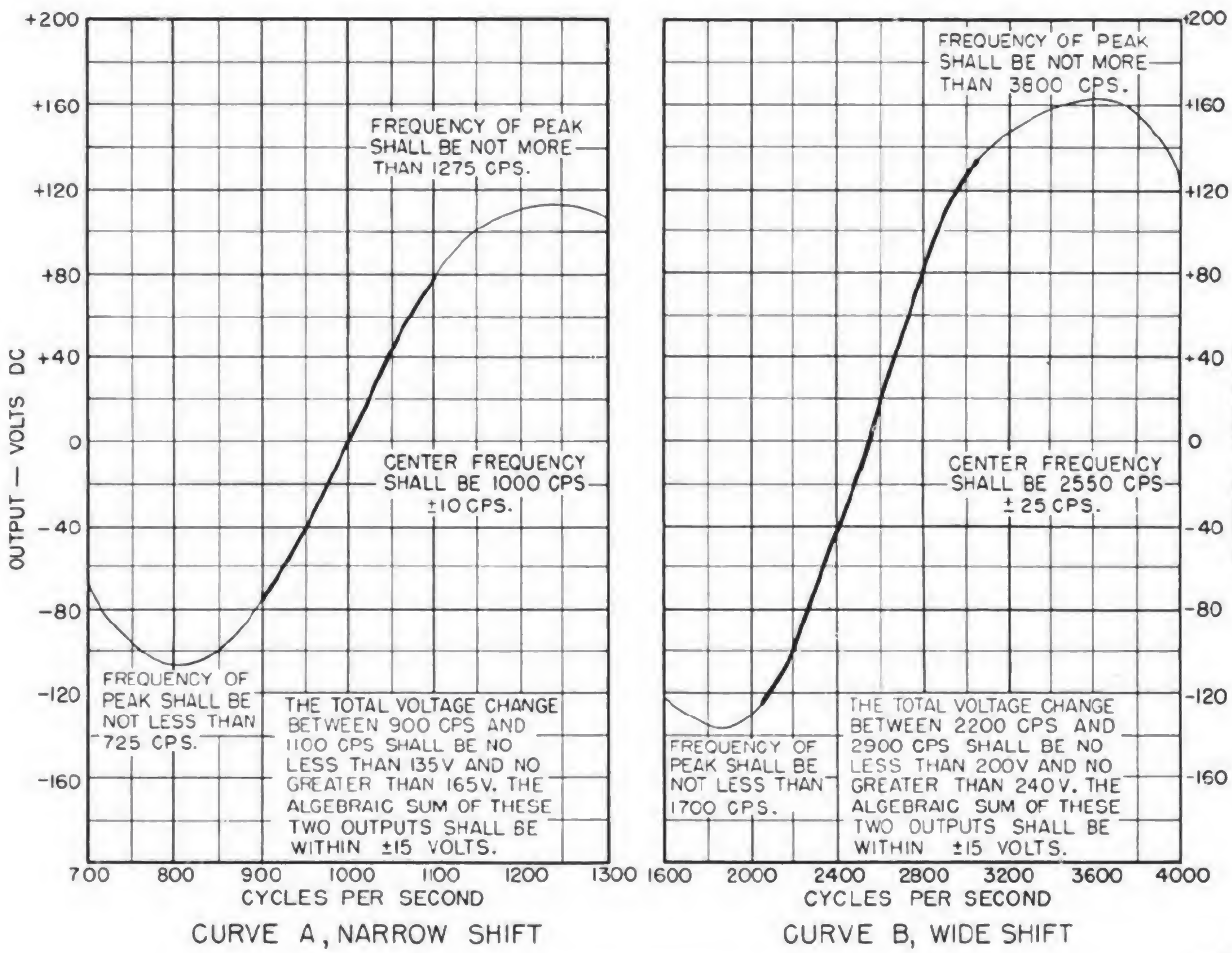

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Figure 16-31.—Discriminator frequency response curves.

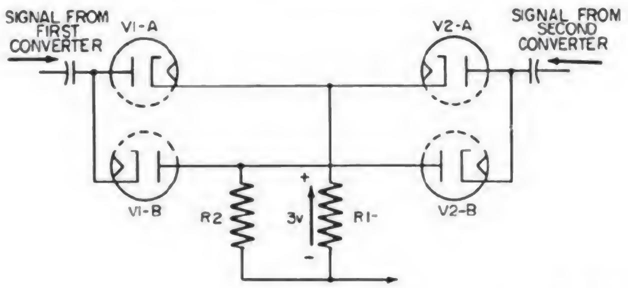

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Figure 16-32.—Portion of selector subunit in Comparator CM-22A/URA-8A.

When frequency-shift signals using narrow-shift operation are to be received, the BFO at the receiver should be adjusted to produce a beat note having an average center frequency of 1000 cycles (curve A, figure 16-31). For wide-shift signals the BFO should be adjusted to produce a beat note having a center frequency of 2550 cycles (curve B, figure 16-31). Where the BFO is not capable of producing this frequency, it may be obtained by slight detuning of the receiver, provided the selectivity is not too sharp.

When employing higher frequency, radio receivers on wide-shift signals, optimum operation is usually obtained with medium selectivity. However, under adverse noise and very weak signal conditions, improved operation can be obtained by using sharp selectivity, provided the BFO can be adjusted to be 2550 cycles higher or lower than the receiver intermediate frequency.

The operating controls for the frequency-shift converter include:

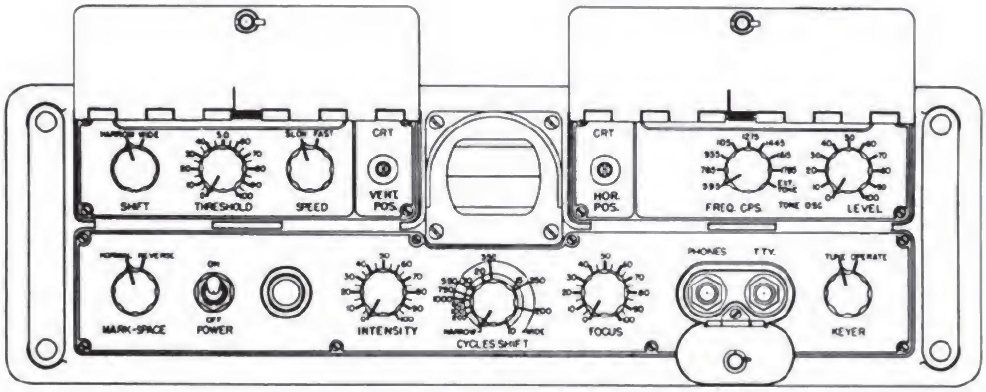
1. Threshold (adjusts bias (axis) to keyer grid).
2. Level (adjusts level of tone output).
3. Cycles shift (adjusts height of oscilloscope pattern and indicates cycles shift).
4. Vertical position (adjusts vertical position of oscilloscope pattern).
5. Horizontal position (adjusts horizontal position of oscilloscope pattern).
6. Intensity (adjusts brightness of oscilloscope pattern).
7. Focus (adjusts sharpness of oscilloscope trace lines).
8. Shift (adjusts discriminator circuits for narrow- or wide-shift input).
9. Mark space (reverses polarity of discriminator output).
10. Speed (selects fast- or slow-keying speed filters).
11. Frequency cps (selects frequency-determining elements for tone oscillator).
12. Keyer (for locking up, or closing of teletypewriter circuit during tuning of the receiver).
13. Power (switches a-c power input on and off).

The operating controls for the comparator include:

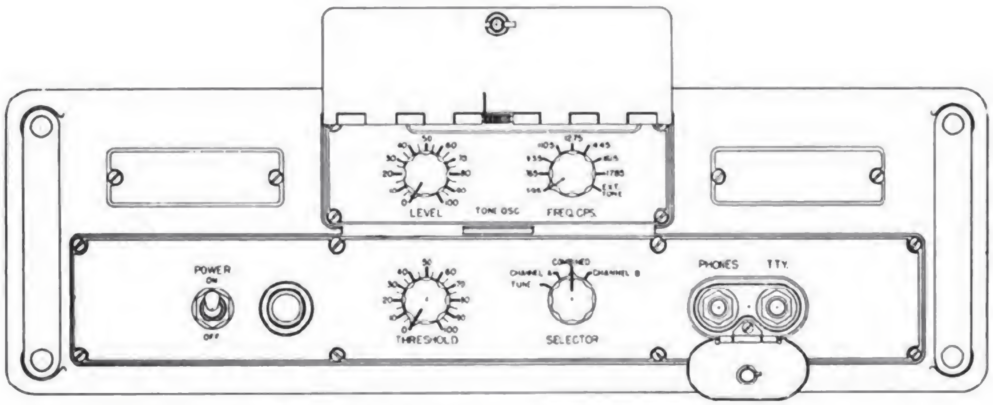
1. Threshold (adjusts bias (axis) to keyer grid).
2. Level (adjusts level of tone output).
3. Selector (selects input to comparator).
4. Frequency cps (selects frequency determining elements for tone oscillator).
5. Power (switches power on and off).

For diversity operation:

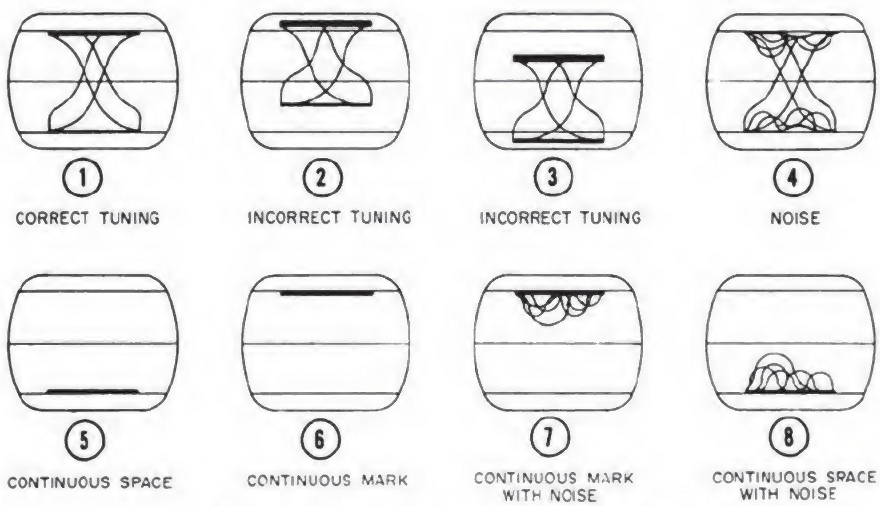
1. Set the comparator selector control to TUNE.
2. Turn the comparator threshold control to ZERO.
3. Throw all power switches to ON and allow sufficient time for the receivers to stabilize.
4. Set the shift control on each converter to the WIDE position; or if the shift width of the signal is known, set the shift control to the corresponding position.
5. Turn the cycles shift on each converter to approximately 800 on the wide range. If the cycles shift of the signal to be received is known, set the cycles shift to the corresponding position on the narrow or wide range.
6. Adjust the other oscilloscope controls as required. These adjustments are summarized at the end of this discussion.
7. Set the speed control on each converter to the SLOW position for keying speeds of less than 60 words per minute or to the FAST position for keying speeds in excess of 60 words per minute. However, under unusual conditions, operation is sometimes improved by switching to the FAST position when receiving less than 60 words per minute.
8. Set the comparator frequency cps to the desired tone output frequency and turn the level control to the required output level when tone output is used.
9. Tune the receivers to their respective r-f carriers and adjust the tuning so as to center the signal pattern on the oscilloscope, as shown in figure 16-33C(1). The tuning of the receivers affects the vertical position of



A FREQUENCY SHIFT CONVERTER CV-89A/URA-8A



B COMPARATOR CM-22A/URA-8A



C MONITOR OSCILLOSCOPE PATTERNS

1.239

Figure 16-33.—Operating controls and monitor oscilloscope patterns for Converter-Comparator Group AN/URA-8B.

the pattern. The cycles shift control on the converter adjusts the vertical size of the pattern. Aural reproduction of the audio output of the receiver is recommended to aid the operator to identify the signals.

For dual diversity reception using two communication receivers, links are provided in the diode detector and AGC circuits that make these circuits common to the two receivers by means of receptacles, jacks, and suitable cabling. The gain of both receivers must be balanced. This action is accomplished by regulating the amount of amplification in the first two stages of the second i-f amplifier assembly of each receiver through adjustment of the diversity gain balance control. This control is a recessed screwdriver adjustment on the front panel.

With a common AGC circuit for both receivers, r-f input signals to both receivers (local and remote) will affect both AGC circuits simultaneously. For example, if the r-f input signal to the local receiver becomes stronger than the r-f input signal to the companion receiver, the AGC bias in both receivers will increase. This action decreases the gain of the r-f and i-f stages of both receivers, thereby decreasing the relative magnitude of the output signal of the companion receiver with its relatively weaker input signal. This action facilitates the selector action in the comparator by emphasizing the difference in voltage between the two receiver output signals.

The oscilloscope on each frequency-shift converter functions as a monitor for tuning its associated receiver to the r-f carriers, as previously described. When the receiver is tuned correctly and the cycles shift is properly adjusted, the pattern on the oscilloscope of each converter should coincide with the upper horizontal line for a mark pulse and the lower horizontal line for a space pulse, as illustrated in figure 16-33C (1). If the receiver is not correctly tuned, the oscilloscope patterns will resemble patterns (2) and (3) in the figure. Under bad noise conditions the patterns will resemble (4), (7), and (8). A correctly tuned steady space and steady mark signal is shown at (5) and (6) respectively.

10. The width of shift being received is indicated on the cycles shift wide or narrow scale when the oscilloscope mark space pattern is adjusted between the upper and lower calibrating lines, as shown at (1). The scale to read is the one that corresponds to the setting of the shift control (figure 16-33A).

11. Set the comparator selector (figure 16-33B) to channel A (upper converter unit, fig. 16-29).

12. Turn the comparator threshold control clockwise until the teletype printer starts to print.

13. Try the channel A converter mark-space selector in both normal and reverse positions (figure 16-33A) and leave it in the position that gives correct position the characters are of the right polarity to control the teletype printer, but in the ogher position the characters are reversed and will not synchronize the control mechanism of the teletype printer. The latter condition results in no intelligence in the printed copy.

14. The teletype printer should now print correct copy (except in the low parts of a fading signal), indicating that channel A is ready for diversity operation.

15. Set the comparator selector to channel B (lower converter (figure 16-29).

16. Turn the comparator threshold control clockwise until the teletype printer starts to print.

17. Try the channel B converter mark-space selector in both normal and reverse positions, as described for the channel A converter under item 13 (figure 16-33A). Leave the selector in the correct position, as described in item 13.

18. The teletype printer should now pring correct copy (except in the low parts of a fading signal), indicating that channel B is ready for diversity operation.

19. Set the comparator selector to COMBINED (figure 16-33B).

20. Adjust the comparator threshold control to the highest scale reading that does not allow noise pulses to cause errors in the copy. A practical way to find this setting is to detune both receivers slightly off their respective r-f carriers to a position where noise alone is received. Then turn the threshold control clockwise to allow the noise to key the teletype printer. Finally turn the threshold control counterclockwise (back it off) to the position where the threshold bias is just enough to prevent the noise from keying the teletype printer.

21. Retune each receiver to its respective r-f carrier (as it was before detuning).

The frequency-shift converter-comparator group is now adjusted for diversity operation, either continuous or intermittent. Except for occasional retuning of the receivers and readjusting for changing conditions, the

equipment should require little attention by the CT M.

With experience in the use of this equipment the art of tuning and adjusting can be developed to the point where the proper settings can be readily recognized from the teletype printer copy and the monitor oscilloscope pattern. Under conditions of bad noise, it is frequently possible to obtain satisfactory teletype copy in diversity operation from signals that audibly are hardly distinguishable from the noise.

When placing the frequency-shift converter-comparator group into operation for the first time, it is necessary to make four initial adjustments on the oscilloscopes associated with each of the converters. Two of these adjustments are semipermanent and need only be checked periodically after they are once set. The other two are panel controls that may have to be readjusted according to light conditions in the room in which the equipment is located.

To make these adjustments on the oscilloscope, (1) turn the receiver off and adjust the intensity and the focus on the converter (fig. 16-33A) to give a clear, fine trace on the screen with the desired brightness; (2) adjust the converter screwdriver adjustment marked, VERT POS, to make the horizontal trace coincide with the horizontal centerline on the face of the oscilloscope; and (3) adjust the converter screwdriver adjustment marked HOR POS, to center the horizontal trace on the screen.

After making these adjustments, turn the receiver on and proceed with the operation of the equipment. During operation the intensity and focus controls should be readjusted whenever necessary to give the clearest possible presentation.

RECTIFIER POWER SUPPLY

Although teletypewriter motors operate on alternating current, a source of direct current is always required for the signal circuit carrying the start-stop code intelligence. Figure 16-34 shows one model rectifier power supply used to rectify alternating current, changing it to DC for the operation of teletypewriters and converters. This rectifier furnishes a power output of 120 volts DC at 1.0 ampere, which is enough to supply many teletypewriters operating simultaneously. The on-off switch, fuses, and voltage adjusting control are accessible through a door in the front of the cabinet.

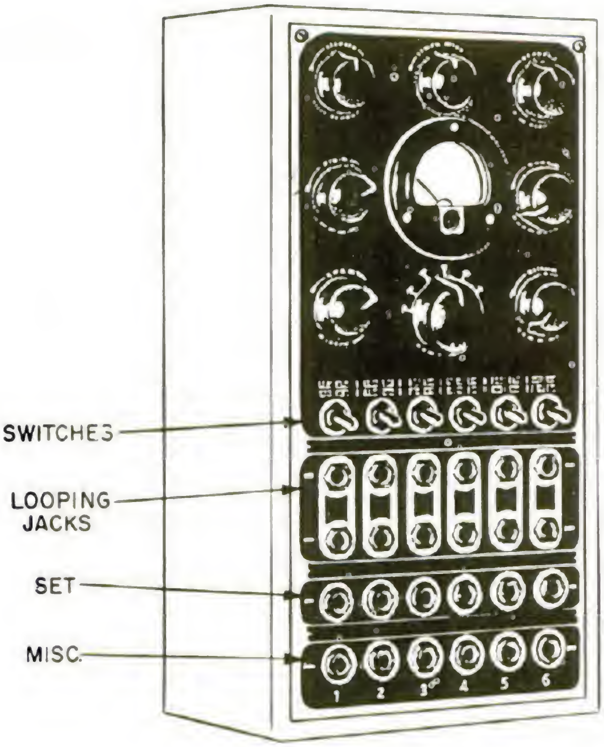
31.33
Figure 16-34.—Rectifier power supply for teletypewriter operation.

TELETYPE PANEL TT-23/SG

The use of teletype panels similar to Teletype Panel TT-23/SG facilitates the interconnection and transfer of teletype equipment aboard ship with various radio adapters, such as frequency shift keyers (where they are not a part of the transmitting set) and frequency shift converters and tone modulation equipments, as previously described. Teletype Panel TT-23/SG is illustrated in figure 16-35.

The teletype panel contains 6 channels, each comprising a looping series circuit of two looping jacks, one set jack, a rheostat for adjusting line current, and a toggle switch for selecting either a local or external source of line current. The panel includes a meter and rotary selector switch for measuring the line current in any channel. There are six miscellaneous jacks to which may be connected any teletype equipment not regularly assigned to a channel. There is a connection block mounted inside the cabinet to which all teletype equipment, radio adapters, and local current connections are terminated.

A schematic diagram of Teletype Panel TT-23/SG is illustrated in figure 16-36A. A single channel is illustrated in figure 16-36B. All radio adapters, such as frequency shift keyers, converters, and tone modulated terminal equipment should be connected to the 1 and 2 (series) lugs. All teletypewriters that are to be in a



1.242
Figure 16-35.—Teletype Panel TT-23/SG.

looping circuit (top two rows of jacks) should be connected to the 3 and 4 (series) lugs. Other miscellaneous teletype equipment may be connected to the 5 and 6 (series) lugs. The bottom row of jacks are used for interconnecting this equipment. The local source of line current, 115 volts d-c, should be connected across the 7 and 9 (series) lugs.

To operate the teletype panel:

1. Turn all line current rheostats counterclockwise to increase circuit resistance to maximum value.
2. Turn on the local line current supply at the distribution panel (not shown in figure 16-36). The green indicator light on the teletype panel will come on.
3. If the desired teletype equipment is wired in the same looping channel as the radio adapter to be used, no patch cords will be required.
4. If the radio adapter supplies its own line current, operate the battery selector switch to the EXTERNAL CURRENT position. If the line current is not supplied externally, operate the switch to LOCAL CURRENT position.
5. Turn the meter selector switch to the desired channel and adjust the corresponding rheostat to give a line current indication of 60 ma.
6. If the desired teletypewriter (for example in channel 1) is not wired in the same looping channel, as the radio adapter to be used (for example, channel 3), insert one end of a molded patch cord (supplied with panel) in the set jack in channel 1, and the other end in either one of the two looping jacks in channel 3 may be made inoperative by inserting a dummy plug (supplied with panel) in the set jack of channel 3, or it may be patched to the looping jacks of another channel (for example, channel 4), by inserting one end of a second patch cord in the set jack of channel 3 and the other end in a looping jack of channel 4.

In any switching operation between the various plugs and jacks of the teletype panel, remember to never pull the patch plug from the machines (set) jack before first removing the other end of the cord plug from the loop jack. Pulling the plug from the set jack first would open circuit the channel and cause all teletype messages in the channel (whether local or remote) to be interrupted. The channel is close circuited as long as the plug is inserted in the set jack. Removing the plug from the set jack first, with the other end of the patch cord inserted in either looping jack, would open circuit the channel because the tip-sleeve connections between the set jack and plug would be interrupted.

The proper procedure is to take the plug out of the looping jack first, or to insert it last. This action maintains closed-circuit operation of all channels in the panel at all times. The switching action of the set jack is illustrated in figure 16-36C.

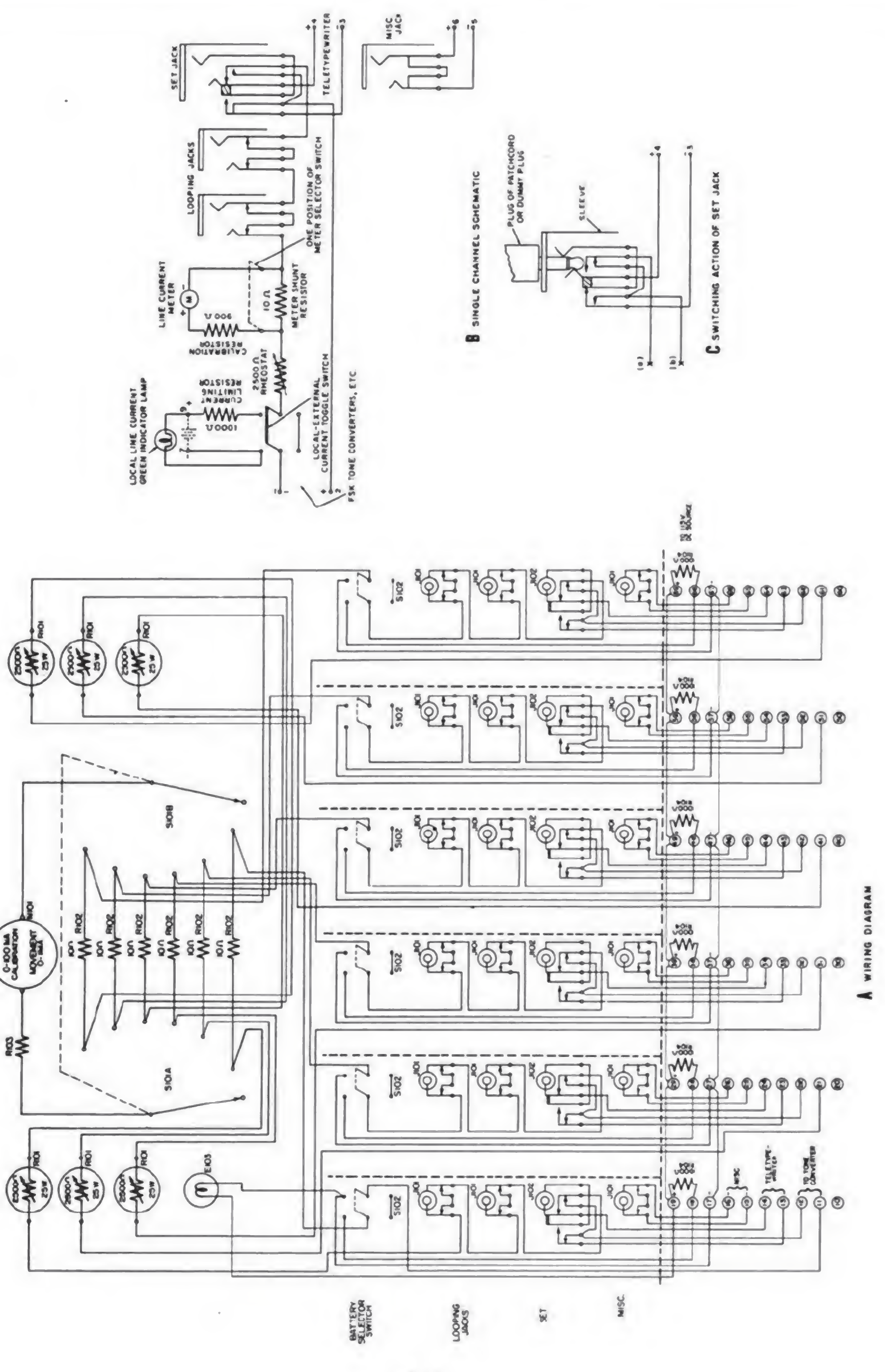


Figure 16-36. —Teletype Panel TT-23/SG (Schematic).

CHAPTER 17

MAGNETIC RECORDER-REPRODUCERS

This chapter introduces the CT M to magnetic recorder-reproducers. These devices are of interest to the Communications Technician because they provide a rapid and convenient means of recording signals, thus enabling the operator to reproduce the signal in its original form at a later date.

RECORDING THEORY

Magnetic recording is a method of impressing a signal on a recording medium by causing a medium to become magnetized to varying intensities in a pattern corresponding to the original signal. To make a magnetic recording, the medium must be a material which will become magnetized and remain magnetized for a long period of time. Modern recording materials retain their magnetism almost indefinitely. In the recording process, the material is drawn past the recording head and must receive a constantly varying signal. The material must have the ability to become magnetized in varying amounts in small sections along its entire length. These sections are measured in microns (1 micron = 1 millionth of a meter). Materials used as recording media are wire, tape made from magnetic alloys, and tape using magnetic particles coated on paper or plastic materials. This chapter deals with the last type of material, magnetic particles coated on paper or plastic; the term "tape" will refer to this material only.

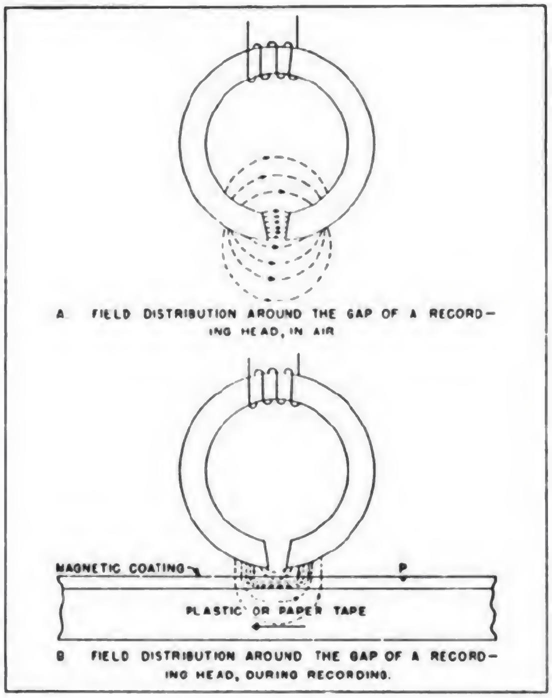
MAGNETIC PROPERTIES OF TAPE

The Magnetic Particles

Plastic-base tape consists of a plastic material which is thinly coated on one side with a mixture of an adhesive with iron oxide particles. The particular size of the particles is one factor which determines the highest frequency that may be recorded, because each particle acts like a small bar magnet—the smaller the particle size, the higher the recordable frequency. Modern tapes contain particles of iron oxide with an approximate average size of 0.4 micron and rarely exceed 0.7 micron. The small particle size not only makes the recording of high frequencies possible, but also makes it easier to obtain a smooth surface, an even particle distribution, and a constant thickness of the coating. These factors are necessary for the production of a high quality recording.

The Magnetizing Field

In the recording process, the tape is drawn past a recording head, which is an electromagnet that sets up a magnetic field (figure 17-1A). The field consists of magnetic lines of force (flux) which are all closed loops having the same direction. The completion of the loop is through the electromagnet. As the signal varies in strength and direction, the field produced by the recording head varies in strength and direction. When the tape passes through the magnetic field (figure 17-1B), the flux lines prefer the path presented by the tape rather than the path offered by the air because of the low resistance (high permeability) of the magnetic particles as compared to the high resistance (low permeability) of air. Assuming the permeability of air as one, many good magnetic materials have a permeability as great as 10,000 and over. The high permeability of the magnetic particles causes a high flux density in the tape when it is in the region of a magnetic field. The greater the concentration of magnetic particles, the higher the permeability of the tape. However, there are only a limited number of flux lines available in the magnetic field (magnetic intensity), and the flux density in the tape decreases as the area of the magnetic



1.245

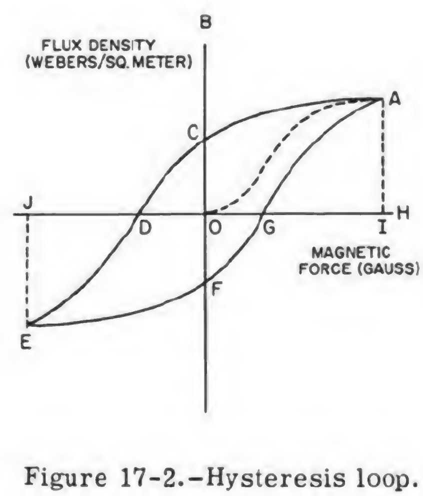
Figure 17-1.—Recording head magnetic field distribution.

medium increases. Therefore, the tape will not become so highly magnetized. The thickness of the coating used on magnetic tape is a compromise of these factors, plus other considerations such as the strength and flexibility of the tape.

Further study of figure 17-1B shows that as particle P of the tape (a completely demagnetized particle) moves past the recording head, it moves from an area of zero magnetic field, through an area of maximum field strength, and out again into an area of zero magnetic field. After making this journey, it might appear that P would either retain all the magnetism it received from the recording head or return to its demagnetized state; neither supposition is correct. The best way to understand what actually happens is to study a hysteresis loop.

Hysteresis

A hysteresis loop is a curve which shows the variation of magnetic intensity to flux density or magnetic induction. Each magnetic material has a hysteresis loop that describes its magnetic qualities; the curves for the various materials differ greatly in shape and area encompassed by the loop. In the hysteresis loop shown in figure 17-2, the flux density increases along the broken curve, OA, as the magnetizing force is increased until saturation is reached at point A. The magnetizing force required to reach saturation (the point at which the flux density no longer increases when the magnetizing force is increased) is represented by OI. When the magnetizing force is reduced to zero, the magnetic material resists the loss of magnetism and does not return along curve OA, but follows a new curve AC, and retains an induced magnetism equal to OC which is called residual magnetism. When the current in the electromagnet reverses, the magnetizing force also reverses and the flux density decreases along CD. When a magnetic material has been completely magnetized, it requires considerable demagnetizing force (a magnetizing force in the opposite direction) to reduce the magnetism to zero. This is called the coercive force and is represented by the line OD. As this magnetizing force increases, the material becomes magnetized to the opposite polarity, and the flux density increases along DE until saturation in this direction is reached at point E. The force to reach saturation in this direction is represented by OJ. As the magnetizing force again reverses, the flux density decreases along EF. OF, which equals OC, is the amount of residual magnetism in this direction. As the magnetizing force increases in the original direction, the flux density first drops to zero at G, due to the coercive force OG, then increases to point A. It is apparent that each time the magnetizing force reaches zero the induced magnetism is not at zero but must be



1.246

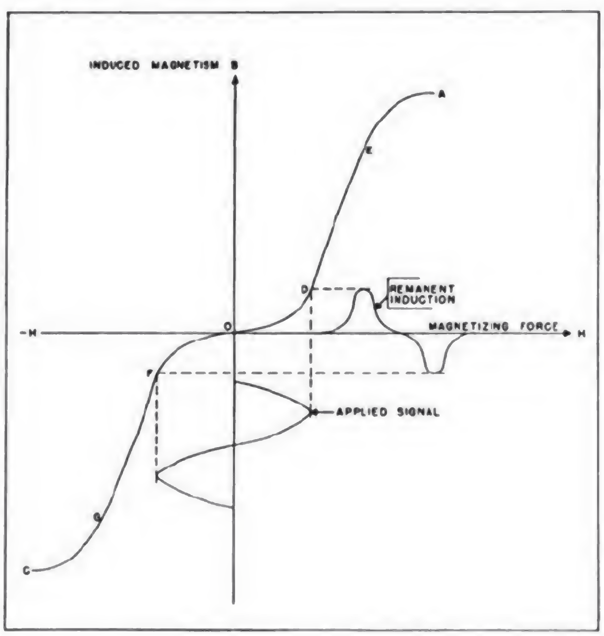
Figure 17-2.—Hysteresis loop.

brought there by a coercive force. If it were not for hysteresis, the magnetization force and the induced magnetism would reach zero simultaneously and magnetic recording would not be possible.

Transfer Characteristics

If the induced magnetism is plotted against the magnetizing force, a curve known as the normal magnetization curve (figure 17-3) results. The value of B increases slowly at first, then rapidly, and then more slowly as the saturation point is approached along line OA. Performing the experiment in the other direction produced the other half of the curve, line OC. It is obvious that this relationship (B-H) is not linear.

As a recording tape is passed over the recording head, each magnetic particle of the tape is subjected to a magnetizing force, which is the field strength produced by the head. A value of induced magnetism will remain in the magnetic particle as it leaves the field produced by the head. This value of magnetism is known as remanent induction. The normal magnetization curve for the magnetic material of the recording tape thus defines the transfer characteristics of the tape.

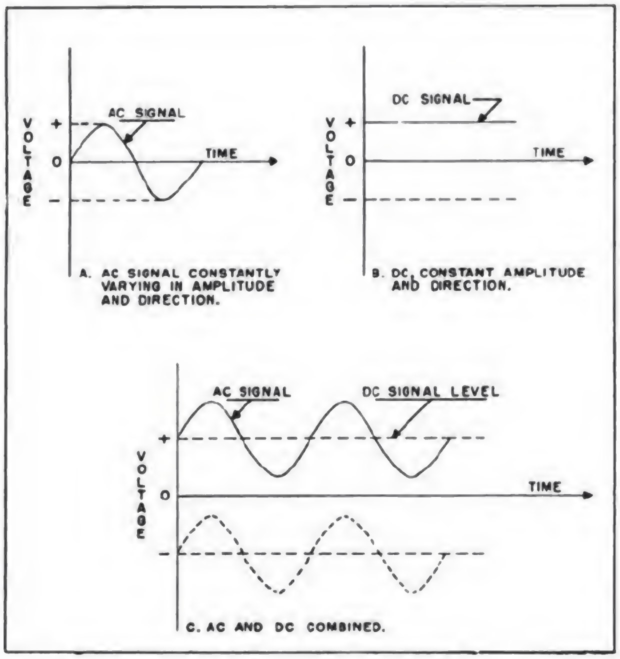


1.247
Figure 17-3.—Normal magnetization curve.

In figure 17-3 an applied signal is plotted on the vertical axis. This signal, representing the field strength produced by a recording head, is the magnetizing force that is applied to magnetic particles along the length of the tape. The resulting magnetization of the tape, which is the remanent induction of the magnetic particles along the length of the tape, is plotted on the horizontal axis. The graph shows that the resulting magnetization of the tape is seriously distorted. This distortion is equivalent to the introduction of odd-order harmonics (third, fifth, seventh, etc.) into a sinusoidal fundamental. During routine recording, it is rare that a pure sine wave is being recorded. Normally, two or more frequencies are present simultaneously, and the nonlinear distortion becomes serious because intermodulation between the signals takes place. The intermodulation causes sum and difference frequencies to be recorded, and the recording no longer is a reproduction of the original signals. If the vertical axis of the diagram could be moved to the center of the linear areas of the transfer characteristic (between D and E, or F and G on the graph), the distortion would be eliminated and a faithful recording of the input signals could be obtained. Elimination of distortion is accomplished by d-c bias or a-c bias.

D-C BIAS

A study of electrical fundamentals shows that an a-c voltage produces a constantly varying signal about a zero axis, as shown in figure 17-4A. D-c voltage produces a signal of constant amplitude and direction above (or below) the zero axis as shown in figure 17-4B. If d-c and a-c are present in the same element at the same time as shown in figure 17-4C. the a-c becomes a signal varying around the d-c signal level. A study of the fundamentals of magnetism will show that the same thing will take place with the magnetic fields set up as the result of the presence of an a-c or d-c signal. A d-c signal causes a magnetic field about an electromagnet which has a constant strength and direction. An a-c signal produces a magnetic field which has varying field strength and reverses direction each time the a-c signal crosses the zero axis. The result of having both an a-c signal and a d-c signal present at the same time in an element, such as an electromagnet, is to cause the a-c magnetic field to either aid (strengthen) or oppose (weaken) the d-c field.



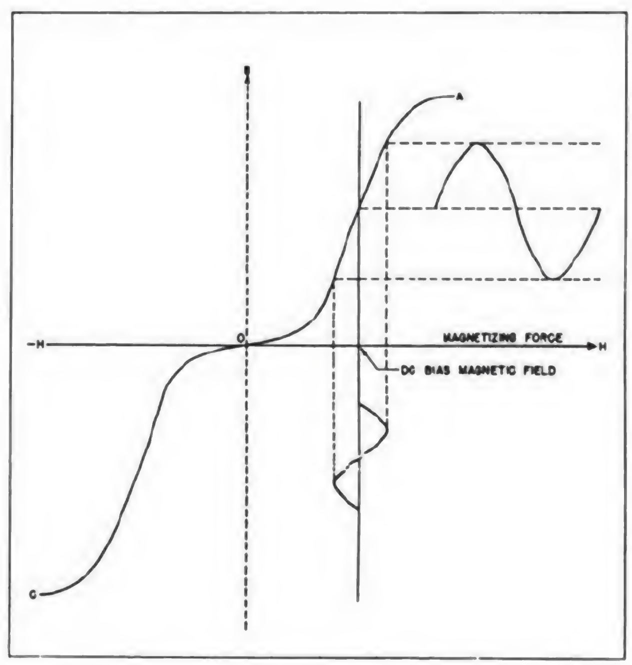
1.248
Figure 17-4.—Effect of a-c and d-c signals.

D-c bias applied to the recording head has the desired effect of shifting the vertical axis of the transfer characteristic into the linear portion of the curve, figure 17-5, by setting up a magnetic field of a given strength around which the magnetic field of the signal to be recorded must vary. The exact value of d-c bias for the magnetic tape being used is determined by experiment. Care must be taken that the volume (amplitude) of the signal being recorded does not cause the strength of the magnetic field to reach the nonlinear regions of the curve. Note that, even when there is no signal to be recorded, magnetization of the tape by the d-c field will still take place. This is undesirable because the magnetization of the tape is equivalent to a signal and therefore becomes noise upon playback. Because d-c bias produces a noisy recording, it is not frequently used and then only for a few special applications.

A-C BIAS

Theory

There are many theories as to how a-c bias actually works—theories too complicated for use in this training course. An analogy exists between the a-c bias and signal combination of a recorder and the carrier-wave audio signal combination of an a-m radio signal. The difference between this signal and the a-m radio signal is that, instead of the audio signal being impressed upon a high frequency carrier which varies about a zero reference level, the high frequency bias is superimposed upon, and varies about, the audio signal. The combined signal is shown in figure 17-6. Note that the variation of the bias signal is centered on, and symmetrically around, the audio signal. One requirement for proper a-c bias is that the bias frequency be from five to ten times the highest frequency being recorded, which provides at least five cycles of bias for each cycle of the signal to be recorded. It has been determined by experiment that at least five cycles of bias must be present to make a-c bias effective. The amplitude of the bias is set at a value that keeps the highest and lowest amplitude of the combined signals entirely within the linear portion of the normal magnetization curve. The recording is made from the high amplitude variation of the combined signals as shown in figure 17-6.



1.249
Figure 17-5.—Effect of a-c bias.

Bias Frequency

The frequency response of a recorder depends principally on the magnetic material on the tape, the recording head gap, and the tape speed. These factors are taken into consideration when the bias frequency is established. As stated above, the bias frequency is made five to ten times the highest frequency that can be recorded. Because of recorder frequency response limitations, the tape is insensitive to the bias frequency; therefore, the bias variations will not be recorded on the tape. The effect of a-c bias is the same as that of d-c bias in that it causes the recording to take place within the linear region of the normal magnetization curve. Unlike d-c bias, a-c bias does not raise the noise level of the recording.

FREQUENCY RESPONSE

The Air Gap

Although the frequency response of a tape is theoretically limited only by the magnetic qualities of the recording material, there are other factors that must be considered if one is to understand the frequency response limitations of a recorder. One of the factors which limits the overall frequency response is the gap width of the recording head. Many types of heads have been used for magnetic recordings, but ringtype heads, constructed on the same principle as the head shown in figure 17-1, are now standard. If the recording head shown in figure 17-1 had no air gap, the magnetic field set up around the electromagnet would be weak and would run in a direction 90 degrees to the field shown, that is, into and out of the paper. A magnetic field of this type would be of little use for magnetic recording. Therefore, an air gap is used to provide a suitable magnetic field. The recording-head air gap is one of the limiting factors in reproducing higher frequencies. Since there must be an air gap, the smaller the air gap can be made, the better the high frequency response improvement in this direction. Heads with gap widths less than 0.0005 inch are not uncommon.

Wavelength-Air Gap Relationship

The gap width effect is dependent on tape speed and bias, but, for the purpose of explanation, these factors will be ignored so that the

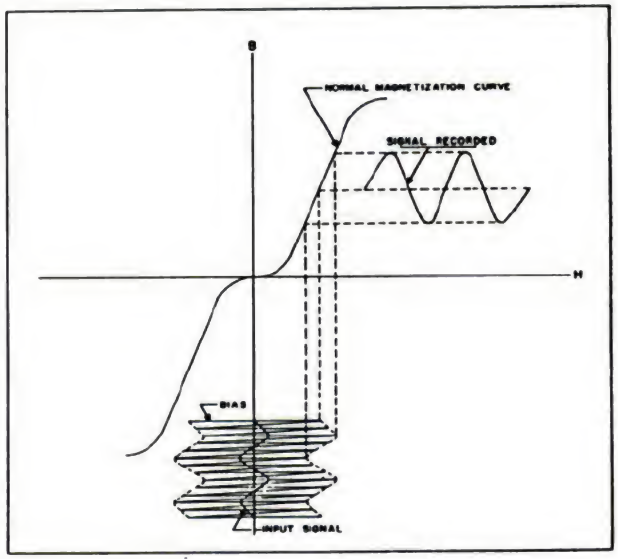


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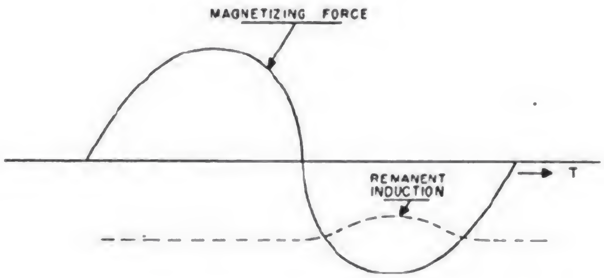
Figure 17-6.—Effect of a-c bias.

effect may be more readily understood. Consider the effect of an air gap that is so large, and the recording frequency of a wavelength so small, that the wavelength is exactly equal to the gap width. The time it takes an area of the tape equal to one wavelength to pass the air gap is assumed to be equal to the period of one cycle of the recording frequency, and the magnetic field set up by the recording head has an abrupt cut-off point. A unit area of the tape will undergo one complete cycle of the magnetic field variation and will, therefore, retain an induced magnetism which corresponds to the last strong magnetic field it passed through, as shown in figure 17-7A. These conditions would result in a signal on the tape which would be equivalent to half-wave rectification. The conditions of the explanation were exaggerated far out of proportion to any situation which might exist when recording frequencies in the audio range, but the point to understand is that the recording-gap effect increases as the recorded wavelength decreases and results in a decrease in the frequency response. Figure 17-7B refers to the relationship between magnetizing force and frequency (both vertical), and gap width as the horizontal.

Frequency-Tape Speed Relationship

The limitations of wavelength-air gap relationship were considered at a fixed tape speed.



1.251
Figure 17-A.—The result of gap effect.

However, increasing the tape speed increases the length of tape passing the record head in the period of one cycle.

It follows then, that for any given frequency the distance between magnetic patterns is directly dependent upon the speed at which the tape moves past the recording head. Therefore, if the frequency to be recorded increases beyond certain values, the tape speed must be increased to give an accurate reproduction of that frequency. This requirement is met in modern tape recorders by making more than one recording speed available to the operator. For example, one recorder presently in use in the Navy will record accurately frequencies up to approximately 15,000 cps at a tape speed of 7-1/2 inches per second. By increasing the recording speed to 15 inches per second this same recorder will accurately record frequencies up to approximately 18,000 cps.

In theory this is an endless progression; increase the tape speed and the maximum recordable frequency is increased. Mechanical considerations, however, limit the maximum tape speed that can be used, (60 ips is not uncommon) and the present trend is toward using increasingly smaller gap widths and improved amplification circuitry to gain increased frequency response.

The Effect of Bias

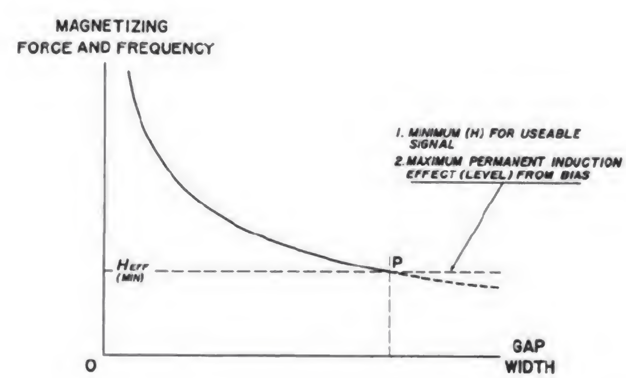
The gap width effect shown in figure 17-7 is essentially correct for a recording using d-c bias. The requirement that the recording magnetic field cut-off abruptly at a given point is not encountered under actual recording conditions. The magnetic field gradually decreases, causing a corresponding gradual decrease in the magnetism induced in the tape. Under recording conditions, the "rectified" signal may not be recorded with sufficient strength to be recoverable.

When a-c bias is used, the gap width effect, using the conditions set up for figure 17-7, is the same as in normal recording conditions, that is, the entire signal would be recorded but at a greatly reduced amplitude (it probably would not have sufficient strength to be recoverable) and with some distortion. The recording of the entire signal is possible because the a-c bias will maintain relatively linear the magnetization curve of the tape, while the tape is in contact with any part of the recording magnetic field, and a-c bias allows the actual recording to take place as the tape passes out of the magnetic field. Therefore, even though each particle along the length of the tape undergoes a complete cycle of the magnetic field, the last field the particle encounters is recorded and the signal is traced out on the tape.

TAPE ERASURE

D-C Erasure

One outstanding advantage of magnetic recording tape is that the recording may be erased and the tape reused a number of times. Erasure of the tape can be accomplished by magnetizing the medium to saturation with a very strong d-c field or with the field from a strong permanent magnet. However, this method is not satisfactory because such a field, while



1.370
Figure 17-7B.—Magnetizing Head Gap Width versus Magnetizing Force and Frequency.

it obliterates the previously recorded signal, leaves the tape strongly magnetized and produces a large amount of noise and considerable distortion in the next recording.

A-C Erasure

A better erasure system is demagnetizing the tape by the use of an alternating field which drives the medium to saturation alternately in both directions and then gradually reduced to zero in the course of many alternations. In order to achieve many alternations in a small gap length, and to prevent any residual fields which will cause an audible note, the frequency of the erasing current is usually between 30 to 80 kc/sec. The erasing current may be supplied by the same oscillator which supplies the bias current. For erasure to achieve complete demagnetization, (1) the head must be free of permanent magnetization; (2) there should be no d-c field in the vicinity (such as from magnetized steel parts, meter movements, etc.); and (3) the wavefore of the erase current must be symmetrical (no d-c component and equal positive and negative peaks).

Automatic Tape Degaussers

Although tape erasure by the recorder is satisfactory for some applications, it requires the tape to be run through the recorder (as in recording) and is somewhat time consuming, especially so when large reels of tape are involved. In addition, most precision tape recorders designed for special applications do not have an erase capability. To erase magnetic tape quickly and efficiently, an equipment called an automatic tape degausser is available.

An automatic tape degausser (such as the one shown in figure 17-8) completely erases signals from magnetic tape by moving the whole reel of tape slowly and steadily into and out of an intense, alternating, magnetic field, while continuously rotating the reel. This subjects all portions of the tape to a thorough degaussing (erasing) action. Heavy duty coils excited by an a-c power source provide the intense magnetic erasing field. The heavy duty coils are mounted in the rear of the degausser housing. One coil is positioned above the tape reel (when the reel is in the erasing field) and the other coil is positioned below the tape reel.

To better understand the degaussing process, consider a single magnetized particle on the tape.

93.40
Figure 17-8.—Automatic Tape Degausser.

During the degaussing process the magnetizing force of the erasing field brings the degree of magnetization of that particle first to saturation in one polarity and then to saturation in the opposite polarity. As the tape moves out of the erasing field and the influence of the erasing field dies away gradually, the degree of magnetization of that particle continuously decreases in alternate polarities and undergoes successively smaller hysteresis loops until a state of zero magnetization is achieved and erasure is complete.

PLAYBACK THEORY

THE MAGNETIZED TAPE

The playback process is essentially the reverse of the recording process. During the recording process, a magnetic medium is magnetized by being passed through a magnetic field that is varying in proportion to a varying signal. During the playback process, the magnetized

tape passes over a playback head that is essentially the same as a recording head. During playback, however, the coil associated with the head is not energized. Instead, the varying field of the tape varies a field through the coil, inducing a current in the coil. This induced current is the recovered signal.

Assuming a tape has recorded a signal, one can imagine that the tape consists of a series of very small bar magnets laid end to end. The field strength of the magnets and the direction of their fields depends on the signal that was applied to the recording head during the recording process.

THE PICKUP

For purposes of illustration, consider figure 17-9 to represent a playback head passing over one of the small magnetized segments of the tape.

As the small magnet passes under the playback head, the magnetic lines of flux pass through the core rather than their normal path through the air because the flux lines find less resistance to the path offered by the core than that offered by the air. As the magnet moves away from the head, the field would then disappear from the core. Because of this motion, a magnetic field was established in the pickup coil and then removed. According to the generator principle, such a change of field in a coil induces a current in the coil. In recorders, this current is amplifield and represents the recovered signal.

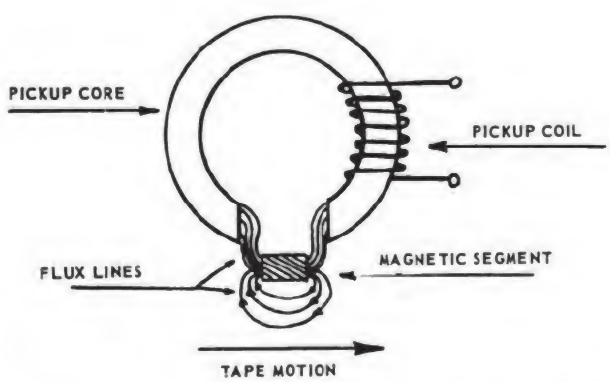


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Figure 17-9.—Playback head magnetic field distribution.

PRACTICAL CONSIDERATIONS

In actuality, the bar magnets of the tape are not separated by any significant distance, but are not essentially joined end to end. As a tape passes under a playback head, the head will see a fairly continuous field rather than a succession of fields. Therefore, if the magnetic segments were originally magnetized so that all of their fields were in one direction and of equal strength (which would happen if a d-c potential alone were used for recording), the playback head would see no change in field strength. Because a change in the field strength through the pickup coil is necessary in order to induce a current, the recording signal must have had a constantly varying potential or no signals will be recovered on play-back.

REPRESENTATIVE RECORDER-REPRODUCERS

DUAL-TRACK

In the preceding sections, tape recording has been discussed only as it applies to a single track; however, few single-track tape recorders remain in service in the Naval Security Group and they will not be discussed in this chapter.

It is possible to record simultaneously more than one track on a tape by using more than one record head, and many tape recorders do have the capability of recording several tracks on one tape.

Magnecord 728/748

The Magnecord 728 (which, except for tape speeds, is identical with the Magnecord 748 pictured in figure 17-10) is a portable, multipurpose, dual track recorder. It uses quarter-inch tape on reel sizes up to 10-1/2 inches at tape speeds of 7-1/2 or 15 ips. The 748 runs at 3-3/4 or 7-1/2 ips and provides good frequency response between 30 cps and 18,000 cps.

AFSAV-75: AN/TNH-11

Another portable tape recorder using quarter-inch tape, the AFSAV-75, is shown with its "Applique" unit in figure 17-11. Without the applique unit it is a half-track recorder; with the applique unit it is a dual-track recorder. The AFSAV-75 uses 7-inch reels at 3-3/4 ips to provide good frequency response between 150 and

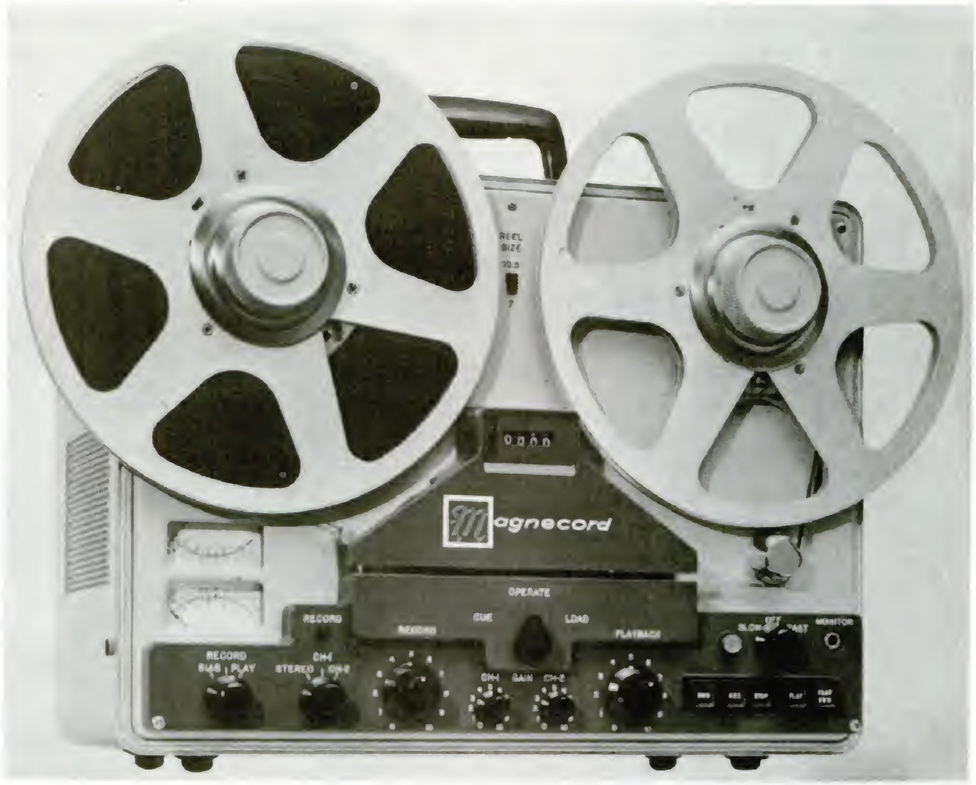

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Figure 17-10.—Magnecord 728 tape recorder.

500 cps. With its accessories (microphone, remote control unit, and foot-switch) it is widely used in the Naval Security Group.

AMPEX S-3160A: AN/TNH-9

The Model S-3160A Ampex, shown in figure 17-12, is a typical rack-mount magnetic tape recorder-reproducer that will be encountered by the CT M. This is a two-channel recorder-reproducer that is used to either record or reproduce two channels of useful information simultaneously on 1/4 inch magnetic tape. This recording is done at tape speeds of either 3-3/4 or 7-1/2 inches per second.

MASTER ELECTRONICS ASSEMBLY—Figure 17-13 is a block diagram of the electronic assembly of the S-3160A. Note that the blocks in the upper portion of the diagram have been separated from the rest of the diagram by a dashed-line boundary. The blocks inside this boundary make up the master electronics assembly. The master electronics assembly represents all of the input and output circuitry necessary for recording or reproducing information on one channel. Notice the Bias-Erase Oscillator (V408) in the lower right hand portion of the master electronics assembly. This oscillator provides the high frequency bias current for the record head. It also drives a large a-c through an erase head. This erase head is actually another record head. With respect to the direction of tape motion beneath the record head, the erase head is placed just ahead of the record head. The current through this head erases any information that was on the tape prior to recording, insuring that when the tape is played back no noise or signals other than the signal recorded will be on the tape.

As to the input-output circuitry, provisions are made for possible adjustment in the amount

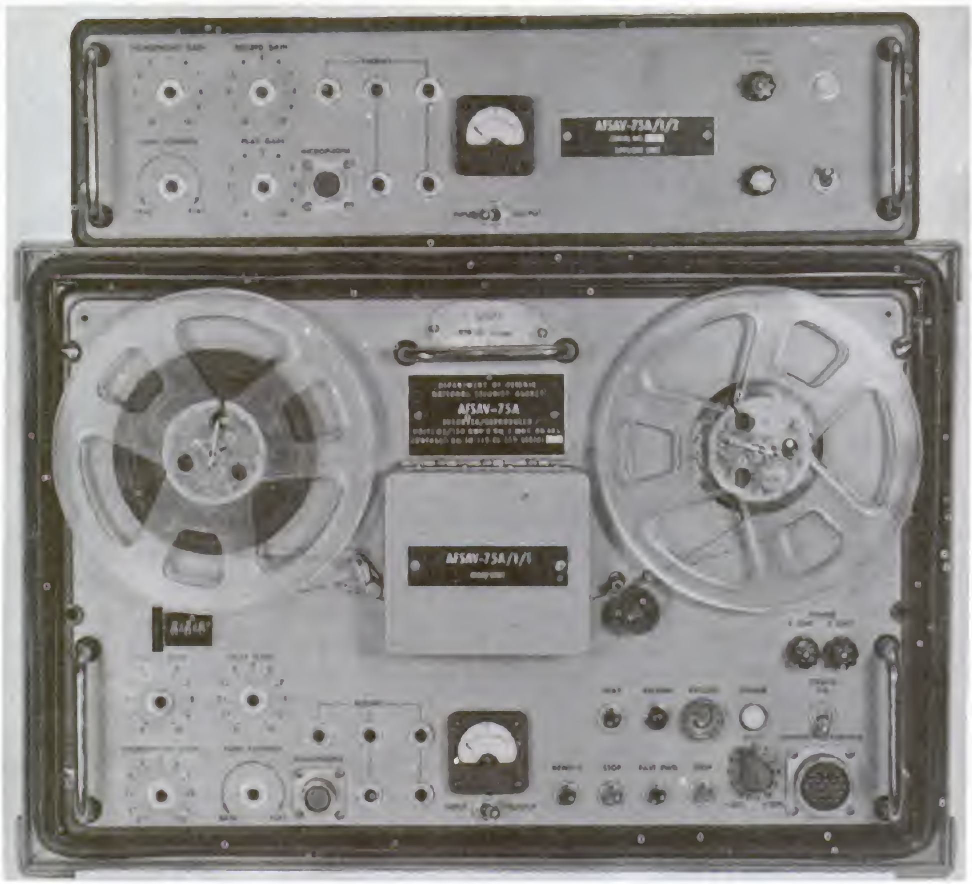

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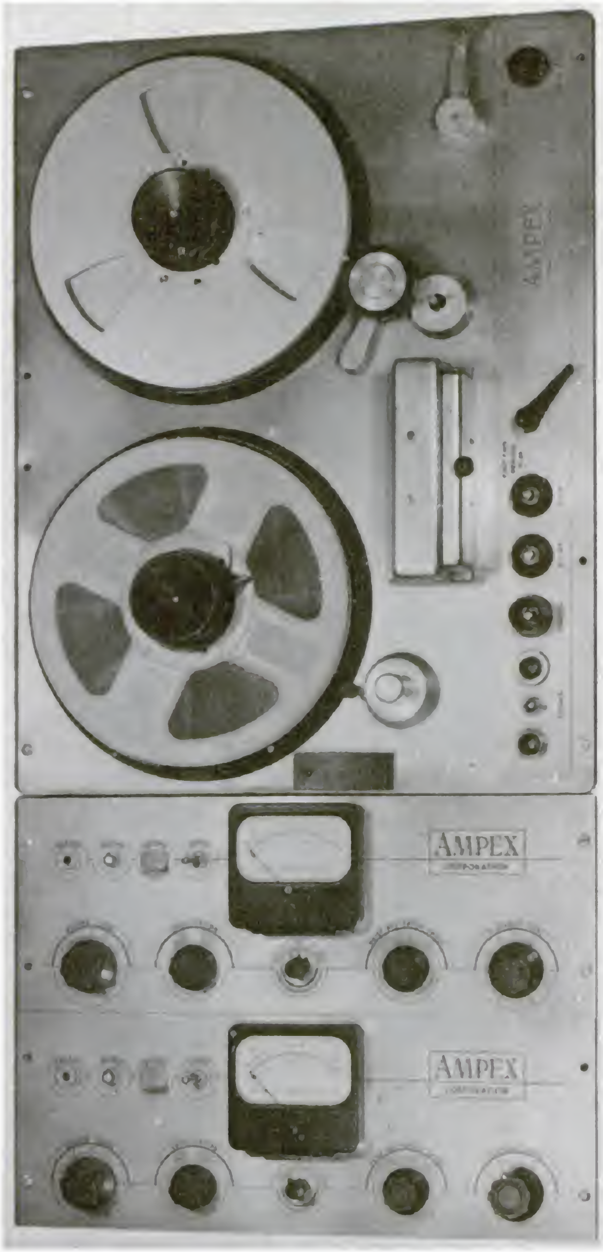
Figure 17-11.—AFSAV-75 tape recorder.

of amplification or attenuation of the input or output signal (R409 or R438) and the bias signal (R460). These provisions are necessary to ensure that the recording takes place on the linear portion of the magnetic material transfer curve. In addition, provisions are made (1) to accept signals from sources of various output impedances (S401 and T401), (2) to vary the response curves of the various amplifiers to compensate for different tape speeds (Record and Playback Equalization Switches), and (3) a meter-switch arrangement to monitor the voltages and currents as adjustments are being made (M401 and S405).

SLAVE ELECTRONICS ASSEMBLY—Consider next the smaller area bounded by dashed lines that is located beneath the master electronics assembly. This portion of the diagram represents the slave electronics assembly. This is actually an abbreviated diagram of the slave electronics assembly. The entire assembly is exactly the same as the master electronics assembly with one exception. The slave electronics assembly does not contain a bias-erase oscillator. Instead, the slave electronics assembly contains a separate bias control (R460) and buffer amplifier (V409) unit. This allows the second channel, the one served by the slave electronic assembly to use the same bias-erase oscillator as the first channel, but still provides separate adjustment for the bias voltage of the second channel. The other adjustments are made on the components corresponding to the master electronics assembly.



1.371X
Figure 17-12.—Ampex S-3160A: AN/TNH-9 tape recorder.

HEAD ASSEMBLY—The portion of the block diagram not yet described is the head assembly. Notice that this assembly is subdivided into three portions—the playback head, the record head, and the erase head. Actually, the playback head and the record head would each contain two core-coil assemblies, one for each channel. Notice also the relative position of these heads with respect to the direction of tape motion. With the heads placed in this manner, it is possible to erase the tape, place a new recording on the tape, and monitor the information that is actually recorded on the tape through the playback system in a single pass of the tape. This is a normal procedure used during the recording process. During playback, the erase head and the record heads are deenergized so that the information on the tape is not disturbed, and only the information placed on the tape at some prior time is picked up.

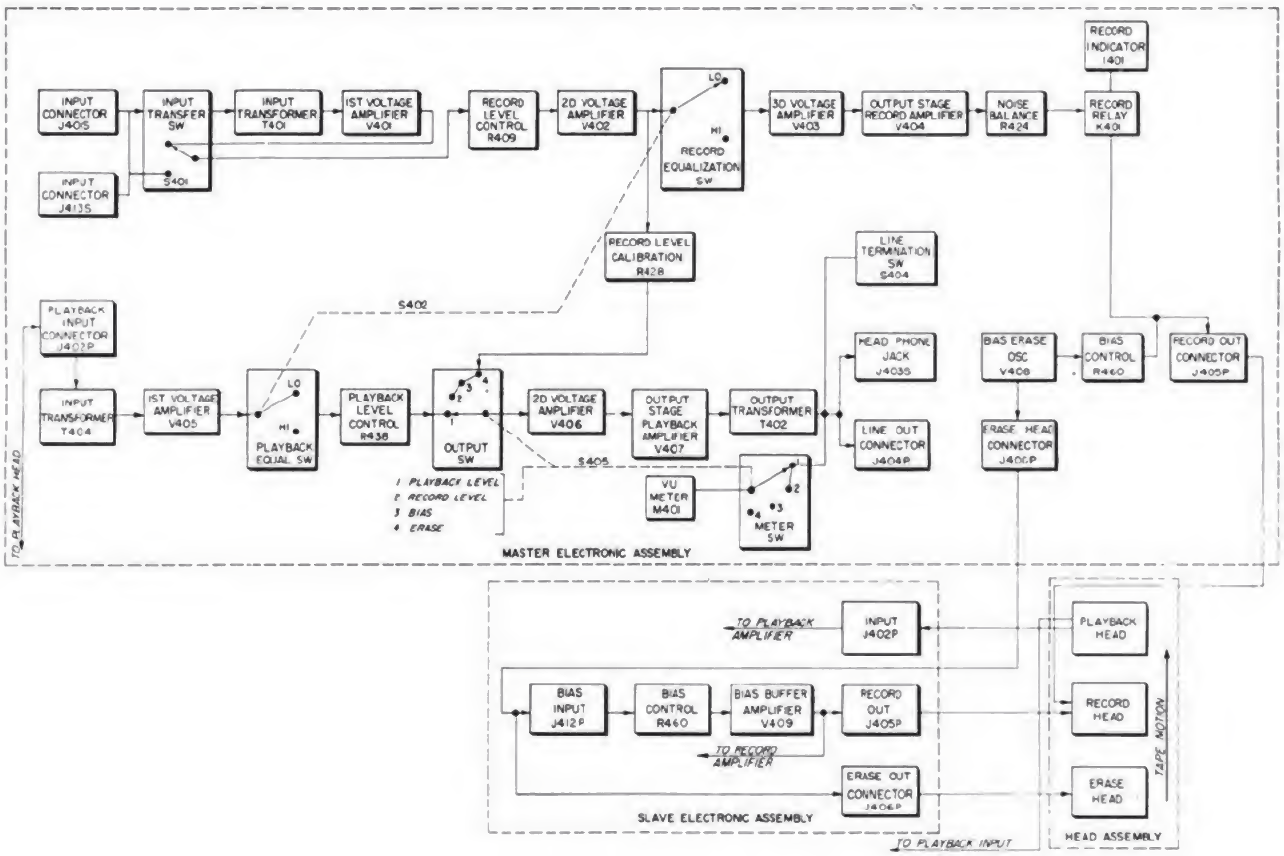
Nearly all magnetic-tape units of interest to the CT M will have these general features. In addition, all will have a somewhat complex mechanical system to drive the tape past the head assembly at a constant speed. This constant speed requirement usually makes it necessary that the installation include a 60-cycle frequency-regulated power amplifier to power the capstan drive motor. Most 60-cycle wall outlets do not receive power from generators having adequate frequency regulation to meet the requirements for stable speed control of the capstan drive motor.

As a CT M, you may be called upon to perform some of the operating adjustments on recorder-reproducers and to perform the maintenance. The actual procedures for such adjustments and maintenance are spelled out in detail in the instruction manual for the individual equipments. Do not attempt any adjustments or trouble-shooting on recorder-reproducer equipments except as specifically outlined in the instruction manuals. Most adjustments are critical for proper operation and adjustments done by "eye" will only lead to more serious trouble.

MULTIPLE-TRACK

MINCOM-CM-100

Some recorders in use by the Naval Security Group will record up to 14 tracks on 1-inch tape. One such multitrack recorder is the rack-mounted MINCOM CM-100 shown in figure 17-14. This recorder is designed for seven track record-reproduce but is capable of being modified for fourteen-track record/reproduce. The CM-100 will accomodate either 10-1/2 or 14-inch reels, with 1/2-inch tape being used for



1.253

Figure 17-13.—Block diagram of electronic assemblies Model S-3160A.

7-track recording and 1-inch tape being used for 14-track recording. Because of its wide range of tape speeds (7-1/2, 12, 15, 30, 60, and 120 ips) and excellent frequency response (400 cps to 1 mc at 120 ips) the CM-100 is gaining wide use in Naval Security Group application.

In multi-track recorders the record heads are placed one beside another (with a laminated magnetic shield between each track) in what is called the "head stack". In effect, each record head acts as a separate recorder with its own amplifier circuits. Figure 17-15 illustrates the head stack of a 4-track recorder and figure 17-16 shows the physical layout of the tape transport of a typical multitrack recorder.

There are times when it is desirable to simultaneously record two or more related signals. Also, in some applications, it is desirable to record, in addition to the signal(s), information such as voice comments, standard time transmissions, or standard reference tone for tape speed check. The multitrack recorder makes possible such multiple recordings.

To minimize overlap or "crosstalk" in multiple track recording, the spacing of record heads is very critical. For example, in a typical 14-track recorder using 1-inch tape, the width of each track is 0.050 inches, and the spacing between tracks is 0.070 inches center to center or 0.020 inches edge to edge. It is obvious then, that multitrack recorders are high precision instruments requiring careful handling and treatment.

1.372
Figure 17-14.—MINCOM CM-100 tape recorder.

AMPEX FR-100: AN/TNH-12

The Ampex FR-100 is a typical multitrack recorder/reproducer that is widely used in the Naval Security Group. A model FR-100 is shown in figure 17-17. A later version of the FR-100 series is shown in figure 17-18. This later version includes a fourteen meter indicator panel for monitoring the input/output of the fourteen record/reproduce tracks. The equipments are designed to either Record or Reproduce; each individual machine accomplishing only one or the other of the two prime functions. The machines operate at 60 ips, through the drive system, designed for both 60 and 30 ips, can be modified to operate at 30 ips, if necessary.

TAPE TRANSPORT.—The Tape Transport Mechanism is the heart of the recorder/reproducer. It not only provides facilities for transporting the magnetic recording tape over the head assemblies but it also provides central tape control and amplifier relay facilities.

Basically, the tape transport mechanism consists of a rigid casting to which all other assemblies are mounted. These major assemblies are a Precision Plate Assembly, a Drive Assembly, two Reel Drive Assemblies (one each for supply and take-up), a Control Circuit and Cluster Assembly, and a Cover Door. The casting is hinge-mounted on the left of the rack, permitting the Tape Transport Mechanism to be swung out toward the technician for access to the assemblies mounted on the rear of the casting. Thus, all maintenance and adjustment procedures can be performed at the front of the rack.

HEAD ASSEMBLIES.—The head assemblies consist of a Head Mounting Plate and the Head Stacks. The heads are mounted on the plate, which is in turn bolted to the precision plate assembly on the tape transport mechanism, in a manner such that the head stacks are aligned precisely with the tape. A 14-contact plug is wired to each head stack and is plugged into a mating receptable on the head connector box. For ease in making connections, a bail is mounted on each plug. "In-line" heads in 14-track head arrangement are normally used on

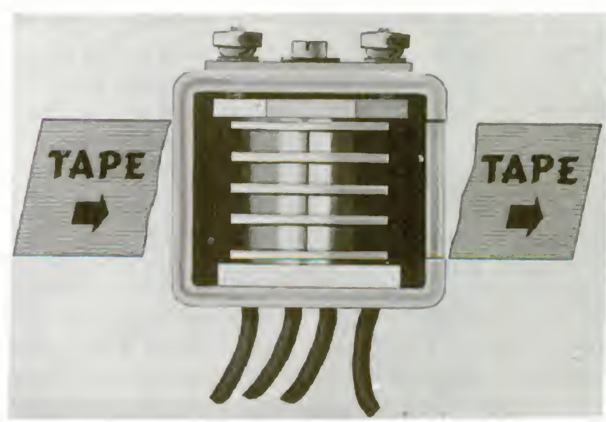


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Figure 17-15.—Head Stack of a 4-track recorder.

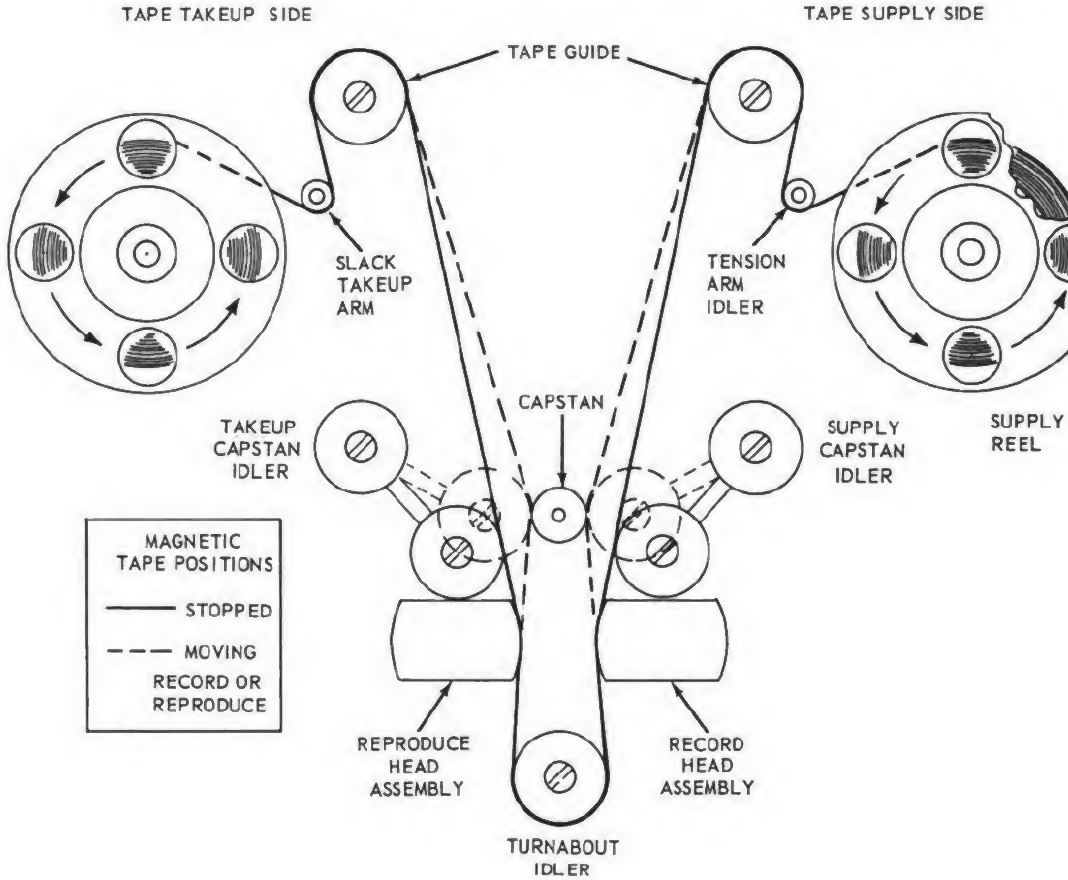

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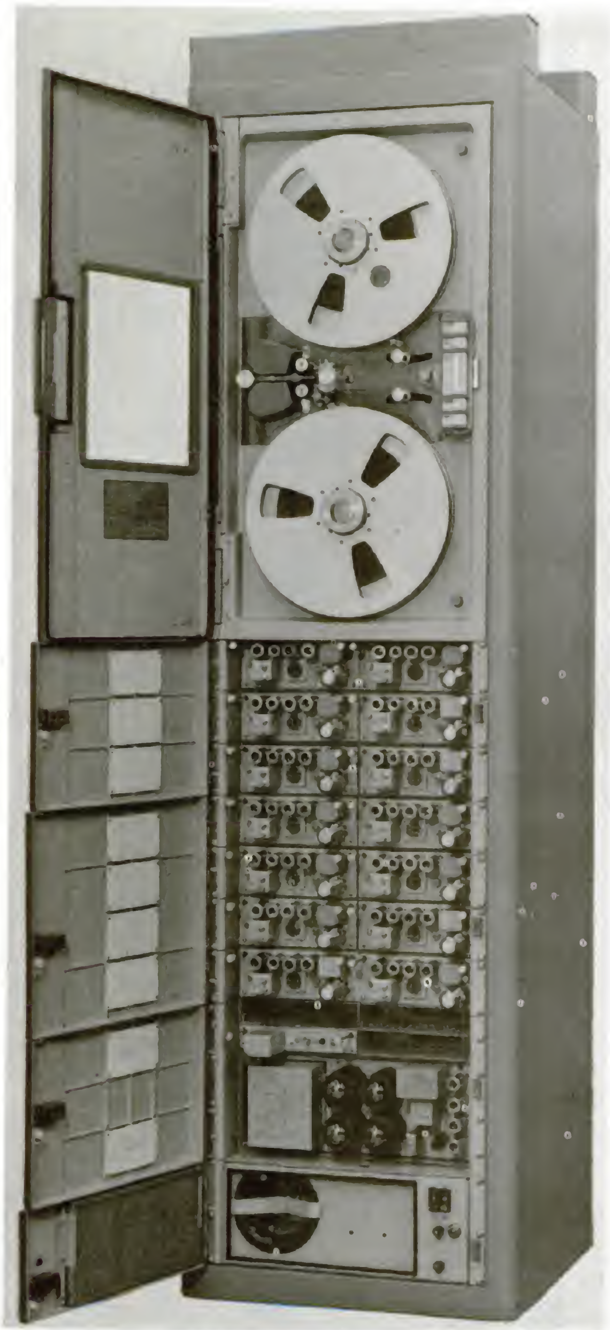
Figure 17-16.—Tape deck layout of a typical multitrack magnetic tape recorder.

computer applications where track-to-track cross-talk is not an important consideration. "Staggered" or interleaved track arrangements are normally used in data recording and reproducing application where track-to-track crosstalk must be kept at a minimum. Obviously, tapes recorded on one type of head stack cannot be reproduced on another if time relationships are to be kept constant.

DIRECT RECORD/REPRODUCE AMPLIFIER.—A Direct Record/Reproduce Amplifier is used for wide-band direct recording. The amplifier is contained in a plug-in, module chassis and is composed of two major assemblies; a chassis assembly and an etched-circuit board assembly. All vacuum tubes, the record relay, and necessary adjustments and test point are located on one end of the chassis; a multiple-contact connector is located on the other end. This connector mates with a matching receptacle when the module is inserted in place in the connecting chassis. The etched circuit board assembly contains all fixed value circuit components such as fixed resistors and capacitors, the oscillator coil, and the like.

All connections to and from the amplifier are made through the multiple-contact receptacle. Power is furnished by the connecting chassis power supply. Signal input and output connections are made to the connecting chassis and then to the amplifier through internal wiring in the connecting chassis.

When the amplifier is mounted in the connecting chassis, the adjustment potentiometers and test points are readily accessible. Record level and bias level adjustment potentiometers, as well as head current test points, are furnished.



1.373X
Figure 17-17.—Ampex FR-100 tape recorder.

Through the use of a special accessory test cable assembly, the amplifier may be connected to the connecting chassis so that the internal circuitry is accessible. The schematic diagram

1.374X
Figure 17-18.—Ampex FR 1200 tape recorder.

contains encircled Arabic numerals; these refer to minor test points on the etched-circuit board assembly, which are similarly marked on the assembly.

HIGH ACCURACY FREQUENCY POWER SUPPLY.—The accuracy of the recorded and reproduced data depends, to a great extent, upon a constant and regulated tape speed. Tape speed is determined almost entirely by Capstan Drive Motor rotation, which is directly proportional to the frequency of the a-c power supplied to it. If this frequency cannot be maintained constant, there will be a difference between the tape speeds during recording and reproduction. The Tape Transport Mechanism has been so designed that any internally-generated errors in tape speed are at an immeasurable level. Therefore, control to prevent variations in tape speed caused by input power fluctuations must be exercised through equipment external to the Tape Transport Mechanisms. This is accomplished through the use of the High Accuracy Frequency Power Supply.

The basic speed control system supplied consists of a precision frequency supply which furnishes the exact drive frequency required for the Capstan Drive Motor, regardless of powerline frequency fluctuations. It consists of a precision oscillator and a power amplifier, with associated power supplies. This system eliminates variations in tape speed due to an inaccurate drive-motor frequency.

CEC-VR-2800

Another 14-track recorder, now being procured for Naval Security Group use, is the Consolidated Engineering Corporation, CEC-VR-2800 series, a typical model being shown in figure 17-19.

CARE OF TAPE RECORDERS

CLEANING

Cleanliness of all components of the tape drive mechanism, which contact the tape, is required for optimum performance of any tape recorder. Cleanliness is of particular importance because tape manufacturers lubricate their tapes. This lubricant gradually forms an oxide coating on the tape transport which may cause distortion of the recorded signal. All

1.375X
Figure 17-19.—CEC-VR-2800 tape recorder.

parts except the head assemblies should be cleaned with a lintless cloth moistened with denatured alcohol. The capstan, tape guides, and idler wheels should be thoroughly cleaned when changing tapes. Care should be exercised not to let lubricating oil contaminate any rubber coated wheels nor should they be touched with the fingers any more than absolutely necessary.

To clean the head assemblies, a clean lintless cloth on a wooden swab-stick should be used. Special head cleaning solvents are available for this purpose and only such solvents should be used. Other solvents could have a detrimental effect on a precision head assembly. The heads should be thoroughly swabbed to remove all accumulations of dirt and oxide. Only a wooden swab-stick should be used as metal of any type could very easily scratch or mar the heads.

DEMAGNETIZING HEADS

Occasionally the heads may become permanently magnetized, usually caused by improper use of the equipment. Magnetized heads can cause a substantial increase in background noise and can impair previous recordings by partially erasing high frequencies during playback.

The operator can help prevent head magnetization by observing the following two rules:

1. Do not connect or disconnect the input leads or the head leads while recording.
2. Do not saturate the record amplifiers with abnormally high amplitude input signals.

If the heads do become magnetized, the procedure for demagnetizing them is as follows:

1. Turn the power switch of the recorder OFF.
2. Select the proper demagnetizing coil for the recorder. Plug the demagnetizing coil into a standard 115V a-c outlet.
3. Bring the tips of the demagnetizing coil to within about 1/8 inch of the record head stack. Straddle the head gap with the demagnetizer tips and draw them up and down the length of the stack three or four times.
4. Remove the demagnetizer slowly from the head stack to a distance of about 3 or 4 feet to allow the a-c field to diminish gradually. This slow removal is very important. Never unplug the demagnetizer while it is near the heads. The collapse of its magnetic field will remagnetize them.
5. Repeat steps 3 and 4 at the reproduce heads and at the erase heads if the recorder is equipped with them.

If the Capstan, tape guides, or other metal parts become magnetized, a few passes of the demagnetizer along their lengths with the slow withdrawal method should demagnetize them.

MAGNETIC TAPE CHARACTERISTICS

MAGNETIC TAPE COATING

A magnetic recording tape consists of a nonmagnetic plastic base with a coating of magnetic oxide bound to one surface. Early tapes were coating with powdered magnetic material containing relatively large particles which gave the tape a highly abrasive surface. These tapes, besides being so abrasive as to cause excessive head wear, had poor frequency response characteristics. Manufacturers solved the problem of particle size by using magnetic oxides with many different characteristics. A low-coercive red oxide was used by the Germans on the Magnetophone, then a high-coercive black oxide became popular, and finally a medium-coercive red oxide was used. After extensive field use and laboratory evaluation, the superiority of the medium-coercive red oxide coating was established, and the manufacture of black oxide tape was discontinued.

The medium-coercive red oxide tape was found to be superior for two important reasons. First, it has a substantially lower erase current requirement which is necessary on some types of recorders. Second, it exhibits a much smaller "memory effect" than black oxide coatings. This "memory effect" is the tendency for a recording to "set" or become increasingly hard to erase as the storage time of the recording increases; then after erasure, the signal returns as background noise or distortion.

EFFECT OF COATING THICKNESS ON FREQUENCY RESPONSE

The field near the air gap of a magnetic recording head diminishes rapidly with distance from the pole tips. It has been shown that the rapid decrease in field intensity in the longitudinal direction of tape motion plays an important part in the recording of high-frequency signals which occupy very short wavelengths along the tape. Successive recorded portions of the tape must pass rapidly out of the effective recording field before the high-frequency signal changes polarity if excessive demagnetization

is to be avoided. The fact that the recording field diminishes rapidly in the direction of the tape thickness is of importance in determing the depth to which the tape coating is recorded. At some small distance from the recording head-gap, the field intensity is no longer sufficient to magnetize the coating; this is called surface effect and is one of the important considerations in the determination of proper bias current for the tape being recorded.

Magnetic tape is normally manufactured in three thicknesses:

1/2 mil: This kind of tape is used in special applications where the size of the tape reel must be restricted, and frequency response is not a primary consideration. This tape has serious "print through" properties and cannot withstand long storage periods without the attendant echo effects. Usually a polyester (Mylar) base is used.

1 mil: The majority of tapes are prepared in this thickness. The base is either polyester or cellulose acetate.

1-1/2 mil: This tape is used in special applications where strength is important. It is usually constructed of polyester, although some acetate has been used.

Whether a tape has polyester or acetate base can be easily determined by holding the reel of tape in front of a strong light; polyester is opaque, acetate is transparent.

RECORDING DEFECTS

DEFECTS IN BASE MATERIAL AND TAPE COATING

Standard recording tapes, while virtually error free, may have defects in the tape coating and in the base material which can cause recordings to be less than perfect. These defects, which usually result in signal dropouts (the loss of all or part of a recorded signal) or noise pulses, cause errors on the recorded tape which may be erroneously traced to the recording system, unless their effects are understood.

Signal dropouts may be caused by a lack of magnetic coating at the point where a pulse is supposed to be recorded. This cause of signal dropout is infrequent except in worn tapes from which the coating has flaked. It is obvious that tapes in this conditions should be discarded. More frequently the signal dropout is caused by the inclusion of nonmagnetic material or oxide clumps in the coating, called nodules.

During recording, the effect of the presence of a nodule is to reduce the sharpness and the intensity of the recorded field. On playback, where the rate of change of the recorded flux is converted back to the original signal, the tape is again held away from the head and the already weak signal is further reduced, resulting in a decrease in output which is called a dropout.

The lack of magnetic material in an area of the tape coating (caused by a pinhole, a particle of nonmagnetic material, or a streak in the magnetic coating which has a deficiency of magnetic particles) will result in a signal dropout and a pulse of noise. An irregularity in the surface of the base upon which the magnetic material is coated, will result in a signal dropout, a noise pulse, or both, depending on the nature of the defect.

LAYER-TO-LAYER SIGNAL TRANSFER IN MAGNETIC TAPE ROLLS

When a length or recorded tape is wound onto a reel, each layer of tape is in the magnetic field of its neighbors. Since any magnetic material placed in a magnetic field tends to be magnetized to some degree by it, each layer is magnetized to some extent by the adjacent layers. The important point is the degree of magnetization, which may vary from totally undetectable, the normal condition, to nearly as large as the adjacent layer, in the case of accidental exposure to external magnetic fields. Such fields (a-c or d-c) can act to increase the transfer from a few db to as much as 30 or 40 db. Most cases of objectionable transfer can be attributed to this cause.

Noticeable layer-to-layer transfer of the signals in rolls of magnetic tape may be avoided by recording below the overload point of the tape, preventing the exposure of recorded rolls to magnetic fields, and avoiding storage of reels in hot places. The existence of transfer at an annoying level is fair evidence of neglect of one or more of the above principles. Noticeable signal transfer is not a necessary evil of tape recording, but merely a possible hazard.

FREQUENCY MODULATION NOISE

The small amount of noise present in magnetic recordings can be thought of as arising from two separate and distinct causes. First are minute magnetic irregularities in the tape

which vary the amplitude of the recorded signal; and second, variations in the speed of the tape, which frequency modulates the recorded signal. The first of these is a well-known phenomenon, which was discussed earlier and is mentioned here only because it is often blamed for the second type of noise.

Variations in the speed of the magnetic tape can produce a variety of effects in the recording. In order to be manifested as noise, the rate at which the tape speed is changing must be much faster than that associated with the capstan or other parts of the drive system. It has been found that the principle sources of f-m noise are the varying frictional forces acting upon the tape as it passes over the recording heads and guides. This action is similar to that of drawing a bow across a violin string, except that the tape, being damped, does not respond with the tone but only the scratch.

There are two distinguishing featurs of f-m noise which can be used to identify it from magnetic noise. Low audio frequency tones are almost completely free from the effect, whereas high audio frequency tones are quite sensitive to f-m noise. Therefore, any noise which increases in intensity as the frequency of the recorded sinal is increased is probably due to f-m causes. Another test for f-m noise is to alter the tape tension or the arrangement of the tape guides and to note the effect upon high frequency signals. In general, an increase in tape tension will result in higher f-m noise.

It has been established that a high degree of friction may result from magnetic tape passing recorder heads or over nonrotating idler rollers. This friction, in some cases, becomes audible and appears as mechanical noise, or "tape squeal," and as a modulated signal on the tape. The varying frictional forces acting upon the tape as it passes over the recorder heads and tape guides produce variations in the speed of the magnetic tape. These speed variations frequency modulate the recorded signal. Extensive laboratory tests have been made to determine the frequency of these vibrations. It was found that the frequency varies widely depending upon the amount of friction, the temperature and humidity, tape tension, and the length of tape span.

It is important that the frictional forces resulting in f-m noise in a recorder be held to a minimum or be eliminated in order to prevent distortion of recorded signals. It is of prime importance that recording equipment be properly maintained.

Performance of routine maintenance, with emphasis on the points outlined below, will hold friction to a minimum. Some common causes of excessive friction are:

1. Excessive tape tension.
2. Misalignment of heads and guides.
3. Buildup of iron oxide and other foreign material on the head surfaces.
4. Buildup of iron oxide on nonrotating tape guides.
5. Grooves in worn heads tend to cause binding of the tape.

HEAD ALIGNMENT AND WEAR

If the reproducing gap is not parallel to the recorded poles on the tape, serious loss of high frequencies may result. For reasons of interchangeability, an attempt is made to align the head gaps on all recording machines exactly perpendicular to the tape. A wandering motion of only a few thousandths of an inch may cause skewing as the tape passes over the head with attendant high frequency fluctuations. Small disturbances such as reel wobble or tension changes may cause the tape to change position as it passes the recording head resulting in serious skewing effects.

Whenever two surfaces rub, wear results after a time. The tape chemist formulates a lubricant into the binder material, or puts a little on the tape surface, and thereby minimizes the wear, but he cannot prevent it completely. The tape must touch the head's surface or a disastrous loss of high frequency response will occur; therefore, the lubricating layer can be only of molecular thickness. Wear, such as that illustrated in figure 17-20, results in the loss of high-frequency response due to the increased gap width in the worn head. When the

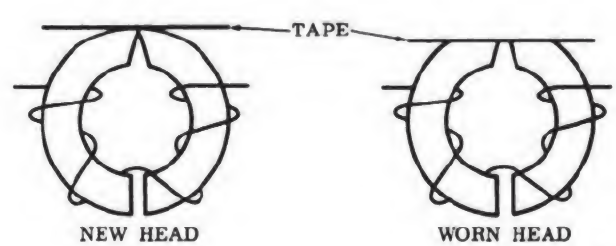


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Figure 17-20.—Increase of gap width due to head wear.

head wear becomes so serious as to cause a frequency response loss due to increased gap width, the head must be replaced.

Grooving is much more rapid than gap length increase, and results principally from the high precision with which tape and recorders are built. Manufacturers try to guide the tape very accurately. As a result, a groove is worn in the head, as shown in exaggerated form in figure 17-21A. Nevertheless, the accurate width and guiding cannot be sacrificed, otherwise skewing could occur, leading to an erratic loss of high frequency response.

If the tape is wider than the groove (shown in figure 17-21B), loss of high-frequency response and signs of poor motion occur at their worst when the tape is only very slightly wider than the groove. This condition will exist using domestic tapes, even though they are manufactured to very close tolerances, but will occur to an exaggerated extent when foreign tapes, which vary greatly in width, are employed.

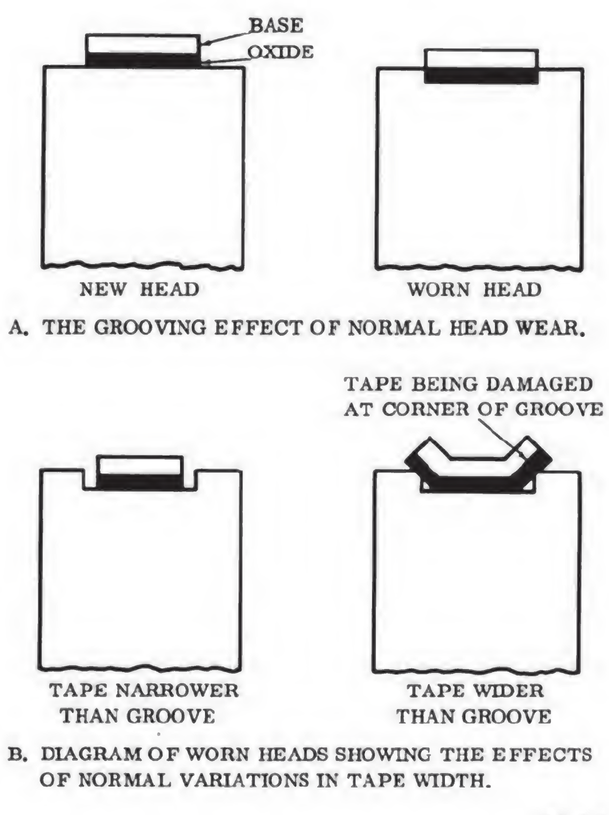

Figure 17-21.—Effects of head wear.

Foreign tapes are more abrasive than the domestic tape and hasten the development of a groove in the head. It is apparent that if narrower tape could be used after a groove was cut, a temporary improvement would occur; this would last only until a narrower groove was cut.

DEFECTIVE TAPE REELS

The pressure caused by tape contraction is one cause of reel warpage, which in turn may cause the tape to be poorly recorded the next time it is used. Many of the ills of magnetic tape recordings thought to be caused by a faulty tape recorder may be found to have been caused instead by faulty tape reels. Tape reels which are warped, out of round, or bent are a major cause of tape skewing, resulting in a loss of frequency response and an increase in f-m noise. Rough, careless handling, dropping, and stacking of reels one on top of the other are all to be avoided.

To guard against poor recordings and ruined tapes caused by faulty reels, the reels should be visually inspected in all phases of their handling. Broken reels obviously should be discarded, and reels with loose screws should be removed from service until the screws can be tightened. In addition to this visual inspection, a periodic alignment check of all tape reels should be made using the XR-3-63 Magnetic Tape Reel Gage shown in figure 17-22.

TAPE WINDING TENSION

Most cases of tape distortion can be traced to excessive winding tension. While the tension on the tape as it is being wound may seem small, a thousand or more layers, each contributing a minute stress, can add up to a tremendous pressure on the tape nearest the hub. If the tape is allowed to weave back and forth during winding, this pressure may accentuate the distortion; therefore, an even wind at moderate tension is desirable. The winding of seven-inch reels on recorders utilizing 10 1/2-inch reels is a cause of excessive tape tension. In order to obtain an even wind of the tape near the end of large reels, the tape tension is set higher than is required for small reels. The tension is set for the windings near the hub of the reel; as the tape is wound out from the hub, the tension of the tape decreases. For example: if the tension required to maintain an even wind on the turns near the edge of a 10 1/2-inch reel is three

ounces, the tension required for the tape at the hub of the reel may be six ounces. Under these conditions, the tension on the tape at a point corresponding to the edge of a seven-inch reel may be in the vincinity of five ounces. If a seven-inch reel is wound on the machine set for 10 1/2-inch reels, the entire tape is wound with more tension than is necessary, and the tape may become permanently elongated.

SPLICING TECHNIQUES, STORAGE, AND MAGNETIC TAPE HANDLING

Despite the universal acceptance of magnetic recording tape in the professional field, some misunderstanding exists concerning the product. There is considerable confusion regarding the life of magnetic properties of sound recording tape. Statements that there is a slow loss of magnetism on sound recording tape are without foundation. In fact, there is a vast reservoir of references in technical literature relating the permanency of materials similar to those used in recording tape. Since a long magnetic life is assured for magnetic tape (unless exposed to stray magnetic fields), the physical life of tape is of more concern. A weak, distorted, or noisy tape can still be used; but if it breaks every few feet, it is useless. Tape life can be increased many times by following the proper methods of handling and storage. The importance of discarding worn-out tape and defective reels (or at least marking them for future disposal if they must be used) cannot be over emphasized. It is desirable to obtain high quality recordings; although tape life can be increased by proper splicing, handling and storage, when a tape (or reel) is in a condition which will substantially lower the standard of the recording, steps must be taken to ensure that is replaced.

SPLICING TECHNIQUES

Most pressure-sensitive tapes now on the market have adhesives which are unsatisfactory for use in splicing magnetic tape. Examples of tapes not satisfactory for splicing magnetic tape include the many brands of transparent cellulose tapes which are made for use on paper. Splices in the wound roll of tape are subject to considerable pressures and temperature variations, and the adhesives used in ordinary pressure-sensitive tapes will creep or bleed around the splice. This is a particularly serious condition, since not only the strength of the splice is impaired but also the adhesive invariably contaminates the magnetic side of the tape, causing adjacent layers to adhere, one to the other, with resultant loss of recorded intelligence in the contaminated area due to poor head contact.

93.46

Figure 17-22.—XR-3-63 magnetic tape reel gage.

The adhesive may also transfer to the heads and guides of a recorder, and thus ruin a considerable amount of tape.

To prevent trouble from the adhesive, a tape specially formulated for splicing magnetic tape is available, guaranteeing trouble-free performance if properly used. These splicing tapes provide thin yet strong splices. The pressure-sensitive adhesive has these characteristics: the bond with the magnetic tape increases under the effects of time and temperatures encountered in use, and the adhesive will not ooze or bleed around the edges of the splice. Any tendency to gum up recording heads or cause the adjacent layers of magnetic film to stick together on the reel is eliminated.

For magnetic tape, the diagonal buttsplice is a tradition. Such splices, properly made, wear without fraying or loosening. To make a perfect splice, the ends of the tape to be joined should be held in some rigid fashion to prevent displacement while the splice is being made. There are three ways to do this:

1. By holding the tape securely between fingers and cutting with a pair of scissors.
2. By laying on a flat surface (soft wood block or slab of rubber) and cutting with a razor blade. This technique can be further improved by placing a straight edge along one side to position both tapes.
3. By using a commercially available splicing block.

The two ends of the magnetic tape to be spliced should be sufficiently overlapped to enable easy cutting and true alignment of both tape ends, providing the recorded information will allow this much tape to be removed. In some cases information recorded is of such a critical nature that no cutting should be done. In this case line up the ends of the tape so both sections are butted and are in alignment with each other, then apply splicing tape and trim. The splicing tape as outlined above, must always be placed on the backing (or shiny) side of the magnetic tape.

The angle of the cut ends is not critical but one must use a diagonal cut to avoid "pop" at the splice point. All angles are measured from the edge of the tape. A 90° cut is always to be avoided. As the angle of the cut edge becomes smaller, the strength, flexibility, and magnetic invisibility of the splice becomes greater. A 45° angle is satisfactory although a 30° splice is approximately twice as strong and flexible.

A piece of standard splicing tape is centered over the butted ends parallel to the splice. After firmly pressing the splicing tape into position, rub firmly with the fingernail or other semi-hard object to press out all air bubbles. The excess splicing tape is trimmed by cutting parallel with but slightly into the magnetic tape. Thus danger of exposed adhesive from the splicing tape is eliminated.

HANDLING AND STORAGE

Ideally, magnetic tape should be stored in a room with the relative humidity maintained between 40 and 60%. If the relative humidity is subject to large variations, magnetic tape can be safely stored in sealed cans. In experiments to eliminate tape squeal, tapes have been subjected to high humidity (practically 100%) for 24 hours and then recorded while damp. This process eliminated tape squeal during the recording process because the dampness acted as a lubricant, but when the tape dried, the tape and in some cases the reel, was ruined. Magnetic tape, especially acetate-based, is subject to expansion when the humidity is high; when a tape is recorded and wound while it is damp, it will contract when it dries building up terrific pressures on the reel.

Magnetic tape will sometimes become brittle after several months storage. The cause of this condition is the prolonged low humidity which exists in heated areas during the winter months. Subsequent storage at normal humidity completely restores the desired tape properties. Just as woodwork shrinks in winter and swells in summer, magnetic tape will shrink or swell with changes in temperature and humidity. Storage of tape at moderate temperatures is desirable. However, tape subjected to extremes of temperature for short periods of time, such as that encountered in shipment, is not permanently affected.

STORAGE HINTS

In general, for long term storage of tape, the following recommendations are applicable:

1. Avoid storing unboxed reels of tape. The original box provides protection against dust contamination and physical damage to the tape edges.
2. Reels of tape should be loosely wound and stored "on edge" or lying flat on individual shelves. Stacking many reels one on top of the

other should be avoided as the weight may distort the reels or damage the edges of the tape.

3. If the relative humidity is subject to large variations, tape storage in sealed cans is recommended.

4. Extremes of temperature should be avoided. If the tape is subjected to extreme temperatures such as in shipment, allow the tape to return to room temperature before running on a machine.

5. Occasional use of the tape improves storage characteristics. Playing the tape on a machine releases strains and adhesions.

6. Avoid excessive tensions in rewinding tape for storage. The tape may become stretched or permanently distorted if wound too tightly.

7. The cleaning of tape is not necessary in normal operation. If dust contamination is excessive, the tape may be cleaned by wiping with a clean dry cloth while rewinding.

CHAPTER 18

RADIO DIRECTION FINDING

Radio direction finding (DF) is the name given to the process of determining the direction from which an incoming radio wave arrives. The direction of arrival, under normal propagation conditions, coincides with the direction of the path of shortest geographical distance (the great circle route) between the direction finder location and the source of the radio wave. Thus, if the direction of arrival of a radio wave is determined, the line of bearing of the source of the wave from the direction finder location is determined.

One of the earliest uses of radio direction finding was for navigation. If a navigating vehicle, by means of a direction finder, obtains lines of bearing to two or more radio transmitters (the lines of bearing will actually be to the transmitting antennas) of known geographical location, a fix of the location of the navigating vehicle is obtained. If the vehicle is moving, the lines of bearing must be obtained within a short time or simultaneously in order to obtain a reasonably accurate fix. The faster the vehicle is moving, the more important the requirement becomes.

If two or more direction finders of known geographical location obtain lines of bearing on a radio transmitter, a fix of the geographical location of the transmitter is obtained. This procedure is the converse of that used in radio navigation. Of course, if the radio transmitter is moving, the lines of bearing must be obtained simultaneously, or nearly so, in order to obtain an accurate fix. The procedure just described has many uses such as locating ships or aircraft in distress or determining the location and movement of enemy or unidentified units (usually referred to as targets) which use radio transmitters.

This chapter explains the basic theory of radio direction finding and discusses the AN/GRD-6 direction finding system.

RADIO WAVE PROPAGATION

The following discussion of radio wave propagation is a review of the material covered in chapter 10 and will emphasize those propagation factors which are pertinent to direction finding fundamentals.

GROUND WAVE PROPAGATION

Ground wave propagation is entirely by vertically polarized radio waves. Any horizontally polarized radio wave is rapidly attenuated by the surface of the earth. For this reason most of the signals propagated in the VLF, LF, and MF frequency ranges are of the vertically polarized type.

Ground wave propagation is not particularly dependent on the time of day or season and hence is very reliable up to the point where the refracted sky wave component can begin to add (constructively or destructively).

It is important to note that the ground wave does not necessarily arrive at the receiving site from the great circle direction of the transmitting antenna. This difference in direction is due to the ground wave being propagated over a medium such as water and then moving on to another medium such as dry earth. This difference in direction will produce an error of a large magnitude when the transmitter and receiving sites are situated on land and separated by a large body of water. The error is sometimes referred to as SHORE EFFECT.

SKY WAVE PROPAGATION

An important consideration in DF by sky wave propagation is the polarization of the reflected or refracted wave as received from the ionosphere. The polarization of the reflected or refracted wave is not necessarily the same as the incident wave. If we assume that the

incident wave is vertically polarized, then the ratio of horizontal polarization to vertical polarization in the reflected wave is known as the "conversion coefficient". The reflected wave may be linearly polarized from the vertical to horizontal or it may be elliptically polarized (the polarization rotates) depending on the conversion coefficient and the relative phase between the horizontal and vertical components in the reflected or refracted wave. The reflected wave is not necessarily in phase or 180 degrees out of phase with the incident wave.

The reflection coefficient varies greatly. It is normally greater for the lower frequencies (550 kc and below) than it is for the higher frequencies. The reflection coefficient is generally greater during the night than during the day, and greater as the angle of the incident wave approaches zero degrees or tangency with the plane of the reflecting layer (longer skips).

COMBINATION OF GROUND AND SKY WAVE PROPAGATION

The arrival of a ground wave and one or more sky waves at a receiving site may cause constructive or destructive addition. The resulting polarity of the received signal may be anything from vertically polarized to elliptically polarized. The type of polarization and strength of the signal depends on the strength of the ground and sky wave, their relative phase, the angle of arrival of the sky wave, the relative bearing (azimuth direction of arrival) of the two waves, and the polarity of the sky wave (it being assumed that the ground wave will be vertically polarized).

A difference in time of arrival at a receiving site between the ground wave and a one hop sky wave is one of the factors in producing a difference in phase relationship. The other major cause for the phase difference is the phase shift caused during the sky wave reflection. Occasionally two waves will arrive at the receiver much further separated in time of arrival than those previously mentioned. This effect may be produced by the signals arriving at the receiver from opposite directions around the world. It is of course, also possible for two sky waves to arrive by a different number of skips at the receiver with a considerable difference in time. The one with the least skips would be expected to arrive first.

All of the factors which affect the polarization, phase, strength, azimuth, etc., of the ground and sky waves must be considered in the design of DF equipment and the bearing accuracy obtained in direction finding. It is important to note that the errors of most direction finding systems are dependent on the sky wave when the sky wave becomes an appreciable part of the received signal.

A radio direction finder is comprised of three essential components or equipment groups —a directional antenna, a radio receiver, and an indicating device. (See figure 18-1.) The component which actually detects the direction of arrival of the incoming wave is the antenna. Therefore, a major portion of this chapter is devoted to the discussion of the theory of direction finding antennas.

DIRECTION FINDING ANTENNAS

GENERAL

Essentially all direction finding systems operating in the HF band and below are designed for measurements on vertically polarized waves. Directional errors often result if the waves arrive with abnormal polarization. (The term "abnormal polarization" implies that polarization is neither entirely vertical nor entirely horizontal.) The amount of error will depend on the design of the system. For some systems, polarization is not critical, but optimum, reliable operation is achieved only if the waves are vertically polarized. The manner in which abnormal polarization affects operation will be pointed out later.

When a conductor is cut by magnetic lines of force, or lines of flux, a voltage is induced in the conductor. In order to cut lines of flux, the conductor must be perpendicular or must have a component that is perpendicular to the lines

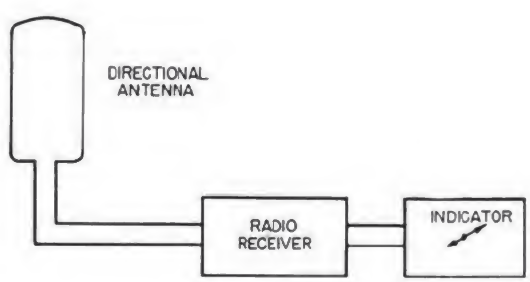

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Figure 18-1.—Essential components of a radio direction finder.

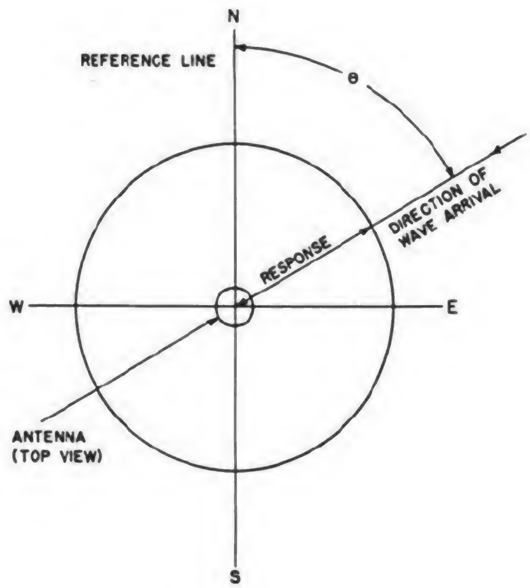

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Figure 18-2.—Polar response of a monopole antenna.

of flux, and the relative motion between flux and conductor must have a component in a direction that is perpendicular to both the lines of flux and the conductor.

The energy radiated from an antenna element is contained in two moving fields, an electric (E) field and a magnetic (H) field. As they travel through space, the lines of the E field and the lines of the H field are perpendicular to each other and the E and H field lines are mutally perpendicular to the direction of propagation according to the right-hand rule. the magnitudes of the E and H lines vary sinusoidally and are in time phase.

A vertically polarized wave has a vertical E field and a horizontal H field. Therefore, the wave induces voltage in vertical conductors only. A vertical wire, or monopole, is the simplest type of antenna. When a vertically polarized radio wave induces voltage in a monopole, the induced voltage is in phase with the incoming wave. (The amplitude of the induced signal will vary with the amplitude of the constant velocity flux (H) lines passing the monopole.) The induced voltage is the same for all directions of arrival in the horizontal plane. (See figure 18-2.)

LOOP ANTENNA

One of the earliest antennas used for direction finding, and one that still finds some application today, is the loop antenna. The response

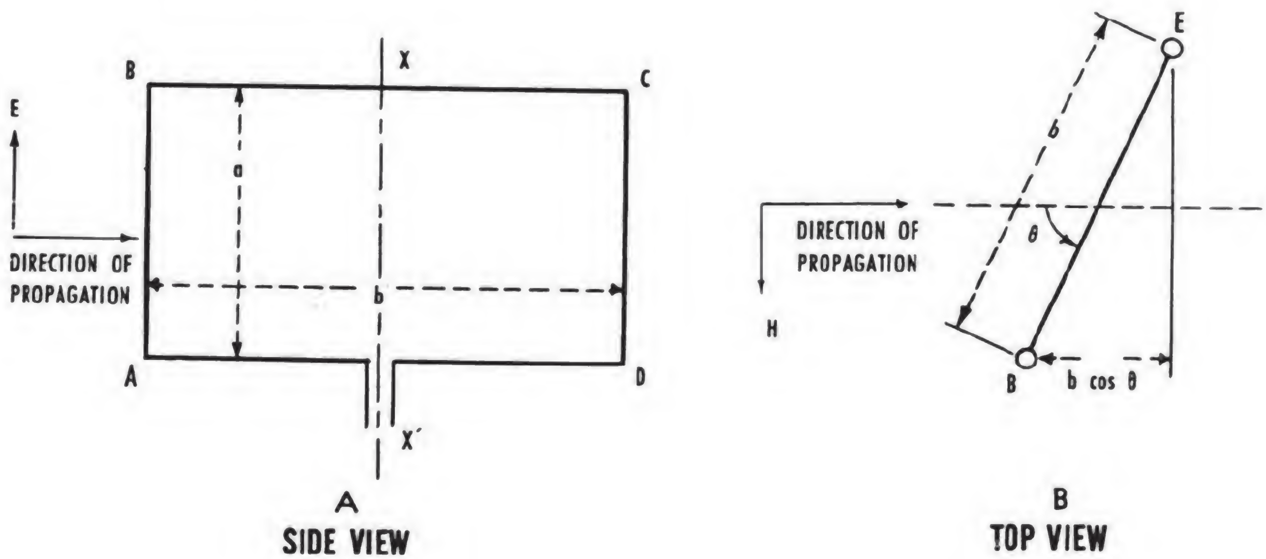

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Figure 18-3.—Loop antenna in a radiation field. A, side view; B, top view.

of the loop antenna is different from that of a vertical monopole. A rectangular single-turn loop with dimensions that are small compared to the wavelength of an incoming radio wave is shown in figure 18-3. As the loop is rotated about the axis X-X', the angle θ between the plane of the loop and the direction propagation of the wave is changed.

If the loop is placed in a radiation field like the one shown in figure 18-3, the H lines of the field cut the sides AB and CD at slightly different times because the wave travels at a constant, finite velocity. At any instant therefore, the voltage induced in arm AB is slightly different from the voltage induced in arm CD. The arms BC and AD are not affected by the H lines of a wave polarized at right angles to them and do not contribute to the induced voltage in the loop because the horizontal members are parallel to the H lines.

If the loop is turned so that its face is perpendicular to the direction of arrival of the wave—that is, $\theta = 90°$—the sides AB and CD are cut by the H lines at the same instant. The voltages induced in arms AB and CD are then the same magnitude and phase and neutralize each other, so that no current flows in the antenna loop.

The instantaneous flux density at any point along the path of arrival varies sinusoidally, as shown in figure 18-4A where the arrows represent the flux density or magnetic field strength of the arriving wave. As the magnetic field at the loop changes in phase, the flux density at the loop changes as shown at L_1, L_2, L_3, L_4, and L_5, which are top views of the loop at various phases (instantaneous times of arrival) of the wave. Actually the loop is stationary and the wave moves, but for ease in representation the loop is shown in five positions along a stationary wave. The loop is seen from the top, and the voltages are induced by the flux lines cutting the vertical sides of the loop, which are in a plane perpendicular to the page.

When the phase of the incoming wave is 0° the loop is at position L_1 with respect to the wave, and the lines of flux cutting the vertical sides of the loop are of opposite polarity. The voltages induced in the two sides are then in opposite directions, and the maximum voltage is developed in one direction around the loop. When the wave phase is 180°, the loop is at position L_4, and again the induced loop volage is maximum but in the opposite direction to that of L_1. When the phase is 90° and 270° (loop

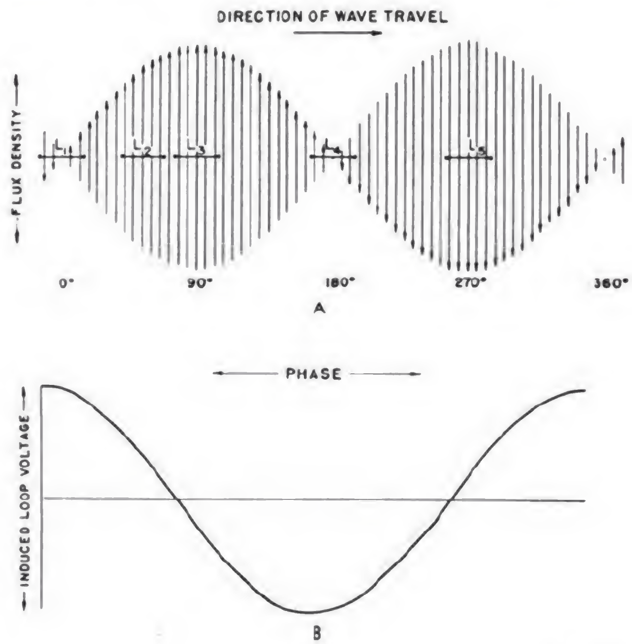

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Figure 18-4.—Induction of alternating voltage in a loop antenna. A, top view of loop at various phases of the incident wave; B, one cycle of the induced loop voltage.

positions L_3 and L_5), the instantaneous flux cutting the two vertical arms is the same in magnitude and direction so that the resultant loop voltage is zero.

The induced loop voltage for a single cycle of the incoming wave is shown in figure 18-4. Notice that the loop voltage differs in phase from the incoming wave by 90°; it is, therefore, different in phase by 90° from the signal induced in a monopole placed at the same corresponding positions. The actual voltage induced around the loop depends on the differences in voltages in opposite arms. Therefore, if the loop is small, with respect to the wavelength of the wave, the resultant loop voltage will be much smaller than the voltage induced in a monopole of the same length as the vertical arms of the loop. The foregoing facts will be illustrated mathematically in the following paragraphs.

Since the E field is in time phase with the H field, the E field of the radio wave can be expressed as $E_{max} \sin(\omega t)$. The expression retains the phase and amplitude relationship illustrated for the H field in figure 18-4. The

mathematical expression which has been derived for the voltage induced in the loop is

$$e = \frac{2\pi NAE_{max}}{\lambda} \cos(\varphi) \cos(\omega t)$$

where e is the induced voltage at the output, N is the number of turns in the loop, A is the area of the loop, E_{max} is the maximum value of the E vector of the radiation field, λ is the wavelength of the incoming wave, and θ is the angle between the plane of the loop and the direction of incoming wave.

Several facts about the loop can be determined from the given equation:

1. As the voltage is proportional to cos (ωt), it is 90° out of phase with the incoming wave which varies as sin (ωt). This was illustrated previously and is important when the voltage induced in the loop is combined with the voltage induced in a monopole.

2. Since e varies as cos (θ), the response is similar to a figure-of-eight pattern, as shown in figure 18-5, which is a polar plot of the response (maximum output amplitude) of the loop versus the angle between the loop and the direction of the incoming wave.

3. The induced voltage is proportional to the area of the loop. This is true for any shape of loop because any loop can be resolved into horizontal and vertical elements. For example, a circular loop can be resolved into tiny horizontal (Δx) and tiny vertical (Δy) elements, as shown in figure 18-6. The horizontal elements are not affected by a vertically polarized wave; the vertical elements are affected in the same manner as the vertical sides of a rectangular loop.

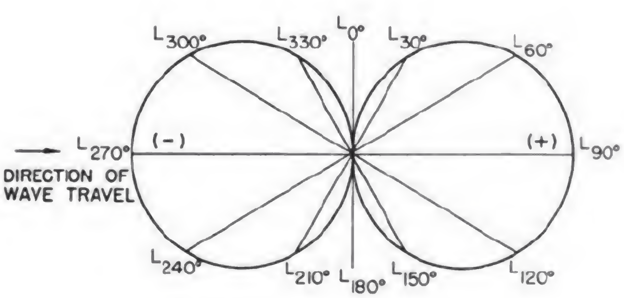

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Figure 18-5.—Polar response of a loop antenna.

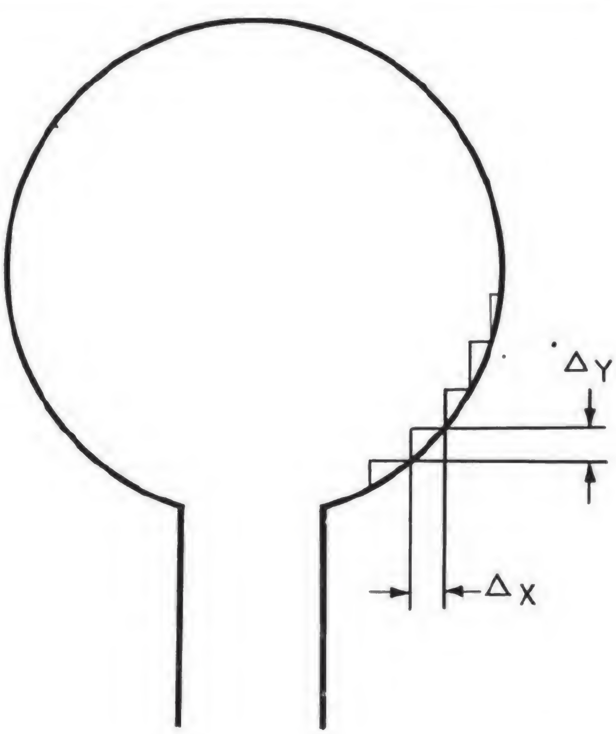

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Figure 18-6.—Loop antenna resolved into tiny horizontal elements (Δx) and tiny vertical elements (Δy).

4. The voltage (e) is inversely proportional to the wavelength of the incoming wave, or it may be said to be directly proportional to the frequency of the incoming wave.

5. An effective height for antennas can be defined as being the maximum voltage induced in an antenna for a unit field ($E_{max} = 1$). Maximum voltage in a loop antenna occurs when $\theta = 0°$. The expression for the effective height, h_e of the loop antenna is then

$$h_e = \frac{2\pi NA}{\lambda}$$

To illustrate, consider a circular loop antenna which is 24 inches (0.61m) in diameter, has eight turns, and is operating at 1500 kc (λ = 200 m). The effective height is then

$$h_e = \frac{2\pi \times 8 \times \pi \left(\frac{0.61}{2}\right)^2}{200} = 0.0734 \text{ m}$$

The equation means that a straight wire (vertical monopole) above ground of only 7.34 centimeters would give the same output voltage.

The directional characteristic of the loop antenna is called a cosine, or figure-of-eight, pattern. When the loop is oriented so that the received signal is a maximum, a small change in orientation produces a small change in signal. However, when the loop is at a null position, a small change in orientation of the loop produces a large change in output voltage. Furthermore, there is a reversal in the phase of the output signal as the loop passes through a null point. For these reasons, in direction finding systems which are based on figure-of-eight types of response patterns, the null points rather than the maximum response points are used to find a line of bearing.

As there are two null positions, 180° apart, the loop can give a line of bearing (the actual bearing and its reciprocal) but cannot determine the absolute direction of the transmitter from the direction finder. The determination of absolute direction, or SENSE, is obtained by adding the output of a vertical monopole antenna to that of a loop antenna. When the two antennas are properly connected, the combined response is not ambiguous.

SENSING

The figure-of-eight pattern of a loop has two null positions for one incident radio wave as shown in figure 18-5. If the outputs of a loop and a monopole are combined in phase, the response of the two antennas is the algebraic sum of their individual diagrams, as shown in figure 18-7. This figure contains four possible responses caused by differences in the relative amplitudes of the monopole and loop outputs. The response shown in figure 18-7C has one sharp null and is the desired pattern.

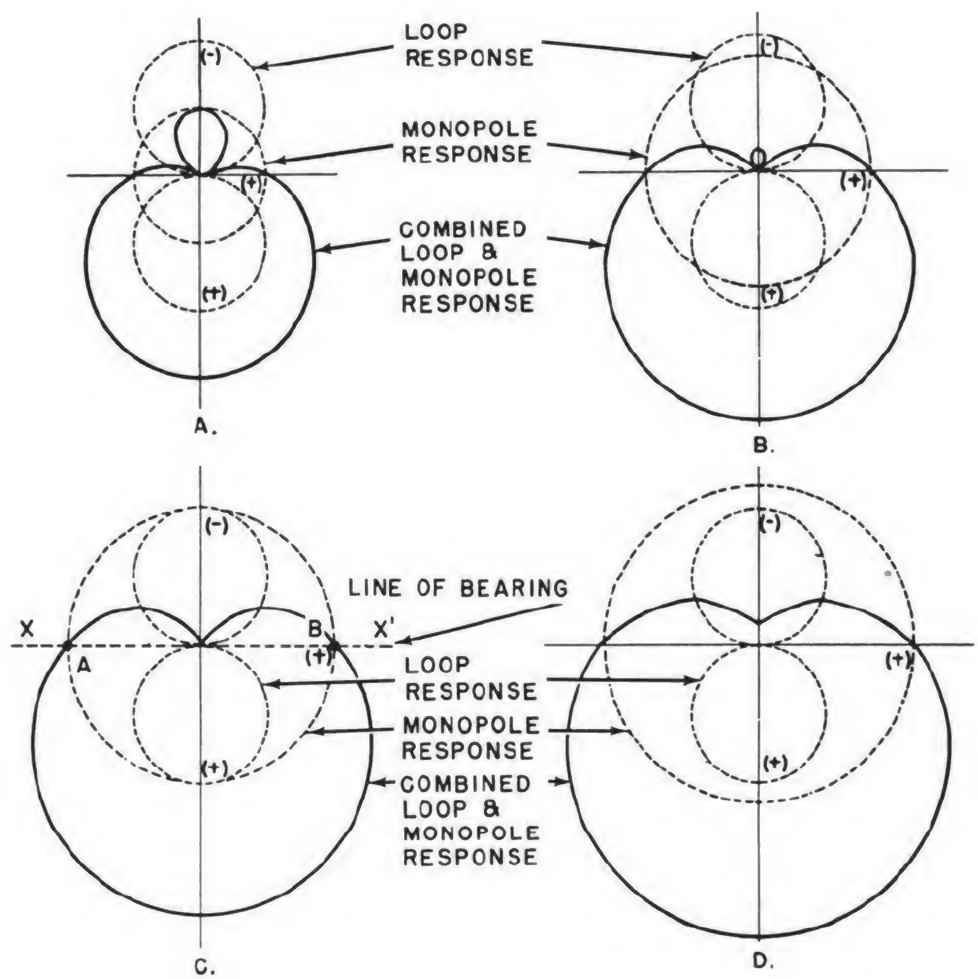
The output of the vertical monopole is independent of the horizontal direction of arrival of the wave. Consider it to have positive (+) polarity. Because the phase of the loop voltages changes as the loop passes through a null, one-half of the figure-of-eight pattern may be said to have positive (+) polarity and the other half to have negative (-) polarity. The addition of the loop and monopole curves gives the responses shown in figure 18-7. The shape of the resultant curves is called a cardioid because it is heart shaped.

The output of the monopole antenna is in phase with the radio wave. The output of the loop antenna, however, is 90° out of phase with the radio wave, which means that the loop voltage is a maximum when the monopole output is zero and vice versa. The cardioid pattern of figure 18-7C cannot be obtained unless the phase of the loop (or monopole) antenna signal is changed by 90°

A block diagram of a simple direction finder is shown in figure 18-8. In operation, a bilateral line of bearing would first be obtained by use of the loop alone. The operation would be accomplished by rotating the loop until a null is found. With the loop in the null position, the sense circuit would be switched in. With the sense circuit in, an output signal would be present, Rotating the loop antenna in one direction would cause the amplitude of the output to increase, and rotating the loop in the other direction would cause the amplitude of the output to decrease. The system is designed so that, by rotating the loop in a prescribed manner, the operator can determine which is the correct null. For example, assume the antenna response for the system is described by figure 18-7C, and the operator believes the radio transmitter to be in the direction of the X on the line of bearing. If he rotates the antenna in a clockwise manner and the signal amplitude increases, he knows he has chosen the correct direction.

CROSSED LOOP (BELLINI-TOSI)

If the loop antenna were rotated continuously, the output signal could be displayed on an oscilloscope to give an automatic indication of bearing. There are certain features of such a system which are not practical. In order to obtain a good null in the response of a loop, the vertical arms of the loop must be identical in every respect. This requirement means that the vertical arms must have identical capacity to ground and to any nearby objects. It is a straightforward and easily accomplished task to balance out differences in the characteristics of the vertical arms for any one particular position of the loop. However, it is impossible, for all practical purposes, to obtain such a balance through 360° of loop rotation. Therefore, it soon became apparent in the design of direction finding systems that some method was desirable for obtaining a bearing on a radio wave without rotating the loop. In 1907, the Bellini-Tosi antenna system, named after its inventors, was developed. The principle of the Bellini-Tosi is used in most



25.105

Figure 18-7.—Response of the com'jined monopole and loop antenna.

present-day direction finding systems which operate in the h-f band and below. This principle produced results equivalent to those previously obtained by rotating a loop antenna. The method used a GONIOMETER connected to a pair of stationary crossed loops.

A schematic of the Bellini-Tosi antenna system is illustrated in figure 18-9. The two coaxially-mounted stationary loop antennas are at right angles to each other. The goniometer is comprised of three coaxially mounted coils. Two are stationary field coils (stators) mounted at right angles to each other; the other is a rotating search coil (rotor) which is inductively coupled to the field coils.

The loop voltages are coupled to the corresponding stators in the goniometer, with the voltage of loop 1 appearing across stator 1 and the voltage of loop 2 appearing across stator 2. If an incoming wave cuts loop 1 in such a direction as to produce maximum voltage in that loop, no voltage will be induced in loop 2. Therefore, there is maximum voltage across stator 1, and no voltage across stator 2. A null will be observed in the rotor voltage whenever the rotor is at right angles to stator 1. If an incoming wave cuts loop 2 in such a direction as to produce maximum voltage in that loop, no voltage will be induced in loop 1. A null in rotor voltage will then occur whenever the rotor is perpendicular to stator 2. One can easily verify that

for radio waves arriving at other angles, such as the wave shown in figure 18-9, there will be a null in the rotor voltage for one angular position of the rotor. (Actually there is a null for two angular positions if 360° of rotor motion are considered.) Thus, the rotor voltage, obtained by induction from the stators connected to stationary loop antennas, has the same response characteristics as the voltage obtained by the use of a single rotating loop antenna. In figure 18-9, the rotor output is inductively coupled to a rotating transformer to eleminate the need for slip rings. Because the loops are stationary they may be permanently balanced to provide optimum response—good nulls. An important advantage of this system is that the antenna can be located at a remote position and coupled by ordinary r-f transmission line to a goniometer located at the receiver.

Since the response of the goniometer rotor is the same as that of a single rotating loop, the bearings are subject to the same ambiguity of 180°. To resolve the ambiguity, the output of the goniometer is combined with that of a monopole antenna after a line of bearing is obtained. This gives a cardioid response from which the absolute direction or sense may be determined. A simplified block diagram of a direction finder which includes a goniometer and an automatic bearing indicator is shown in figure 18-10.

LIMITATIONS OF LOOP ANTENNAS

Thus far it has been assumed that the incoming radio wave is vertically polarized, thus having all its H lines parallel to the earth's surface. If the wave were horizontally polarized, the H lines would all be perpendicular to the earth's surface. The response of a loop antenna to such a wave would also be a figure-of-eight type of response, but the nulls would be displaced 90° from those caused by vertically polarized waves with the same directions of arrival. If the incoming wave arrives with some other polarization—neither vertical nor horizontal—the nulls are displaced by some angle between 0° and 90°.

At the lower frequencies (lower portion of the m-f band and below), radio wave propagation is essentially all due to the ground wave, and thus vertical polarization is always present. However, if the frequency of the radio wave is increased, a significant portion of the wave may arrive by means of the sky wave and will have a horizontally polarized component—the H lines will have a downward velocity component. Thus, a voltage will be induced in the horizontal arms of the antenna with a resultant loop voltage at angles of arrival which ordinarily result in a null. Consequently, the null is displaced and large DF errors result. Errors due to abnormal

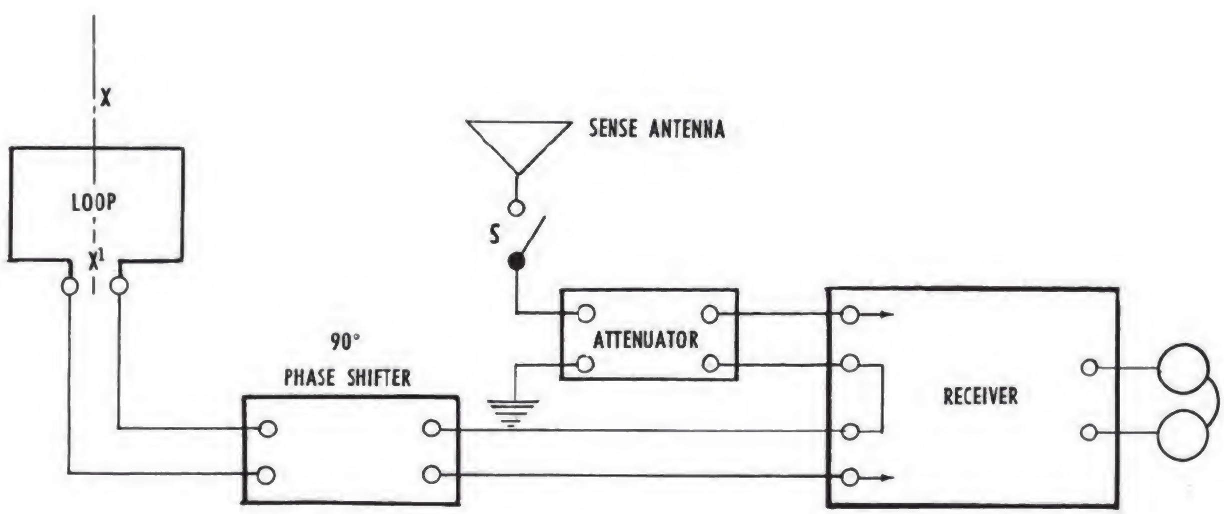


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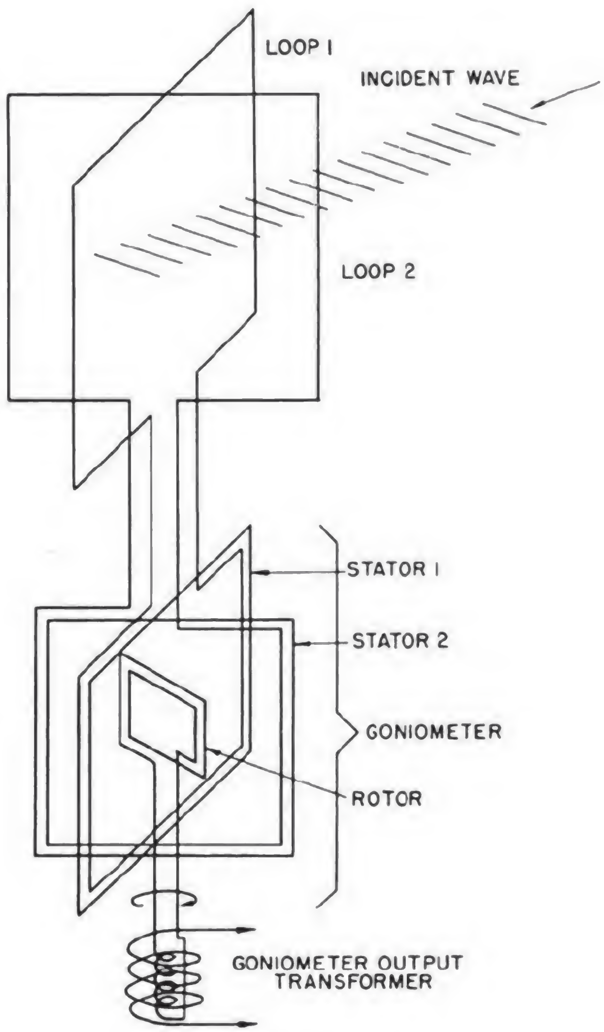
Figure 18-8.—Block diagram of a circuit for obtaining unilateral and bilateral bearings by means of a radio direction finder.



25.107
Figure 18-9.—Schematic diagram of a goniometer used with crossed loops.

polarization of the incoming wave are known as POLARIZATION ERRORS. The effects of polarization error were first experienced on m-f direction finders at night because of the increased effect of the sky wave at that time. Therefore, polarization errors are also referred to as NIGHT EFFECT.

SPACED LOOP ANTENNAS

One method to compensate for polarization errors is to use a SPACED LOOP ANTENNA. A spaced loop antenna consists of two loops arranged parallel to each other on opposite ends of a boom which can be rotated about its center. The outputs of the loops are connected such that the loop voltages due to horizontally polarized components of incoming waves tend to cancel. The response pattern of the spaced loop antenna has four minima. However, the principal nulls—the pair in the plane of the loops—are much less affected by the horizontal component of the incoming wave than the nulls of the single loop. Spaced loop antennas are no longer widely used in Navy direction finding systems.

ADCOCK ANTENNAS

Because the loop antenna is generally useful only for vertically polarized ground waves, a different type antenna arrangement is necessary for direction finding in the h-f band where essentially all reception is due to the sky wave. The large polarization error inherent in the use of loop antennas for direction finding is caused by the horizontal elements of the loop. Because the only practical purpose of the horizontal members of the loop is to connect the vertical members in series (and to give physical rigidity in systems where the antenna is actually rotated), the directive response of the loop will not be affected if the horizontal members are shielded or removed completely. Directive loop antennas in which the horizontal conductors are shielded or removed are called ADCOCK antennas. Adcock antenna systems are used primarily for h-f and v-h-f direction finders. One type of Adcock system will be discussed in detail when the AN/GRD-6 system is discussed.

Figure 18-11 illustrates the SHIELDED U-ADCOCK antenna. The upper horizontal member has been removed completely, and the bottom horizontal member has been shielded. The resultant antenna consists only of vertical members. The directive pattern will be the same as a single turn loop with dimensions of width (w) and height (h).

The direct coupling illustrated in figure 18-11 can be replaced with transformer coupling as illustrated in figure 18-12. This arrangement is called the COUPLED ADCOCK antenna. The wires between the vertical elements and the receiver need not be shielded because they are close together and in opposite phase, thus causing their pickup to cancel.

Adcock antennas may be mounted so that they can be rotated in the same manner as described for the rotatable loop. In most present-day

systems, Adcock antennas are erected in pairs at right angles and used in conjunction with goniometers similar to the crossed loop system previously discussed.

The response of the U-Adcock antenna is the same as for a single loop antenna as illustrated in figure 18-2. This response pattern is repeated in figure 18-13 with geographical references of direction. With a transmitter in the direction of N-S, the output of the antenna is maximum; in the E-W direction the output is at zero or null. The line-of-arrival of an incoming radio wave may be determined by positioning the U-Adcock for a null, or by using a fixed four-element array and a goniometer to determine a null, as previously described for loop antennas. Sensitivity and bandwidth are limited, in a conventional four-element Adcock array, by the antenna spacing; however, large spacing is required for good sensitivity down to the lowest frequency. The spacing of the elements also contributes some error, called spacing error, or octantal error, which will be discussed in the following paragraph. By using a system of eight elements it is possible to increase the spacing up to one wavelength at the highest working frequency. Such a system can result in less than two degrees of spacing error and increases sensitivity and bandwidth. Mutual coupling between elements does not affect the DF accuracy because of the symmetry of the system. The mutual effect is further minimized by using elements having a low reactive component throughout the frequency range.

A simple, or single-stage, goniometer is shown in figure 18-14 as it would be wired for use with a four-element U-Adcock array. By the use of this system, the response characteristic of a four-element U-Adcock and a goniometer, with respect to the goniometer rotor position, is identical to that of rotating a two-element U-Adcock antenna. However, there is an inherent error in the system because the directive pattern of a pair of spaced U-Adcocks is not a true cosine function. The distortion of the response pattern is due to the spacing of the elements. When the noncosinusoidal output of the spaced Adcock array is combined with a goniometer having a true cosinusoidal characteristic, an "octantal" error results (figure 18-15). Inspection of the error curve shows the error to be maximum at 22-1/2° from 0°, and to repeat a maximum error every consecutive 45°. To cancel this error, an identical four-element spaced Adcock array is mounted at 45° to the first array. (See figure 18-16.) Because of the 45° displacement, the octantal error of the new antenna will be displaced by 45° from the first antenna and will appear as the dotted curve shown in figure 18-15. In the AN/GRD-6 system,

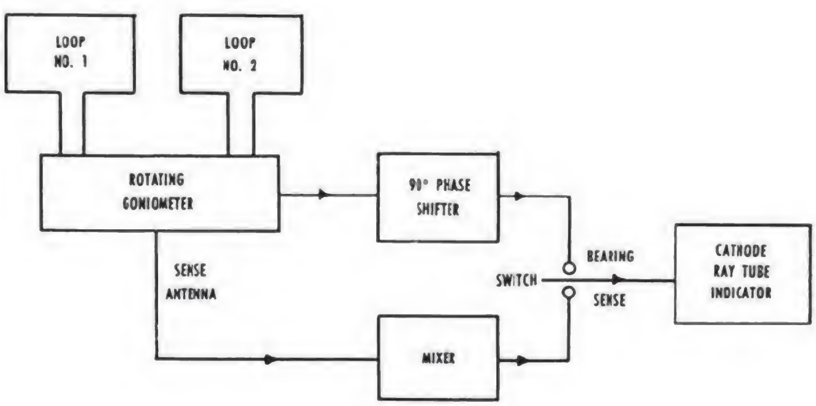


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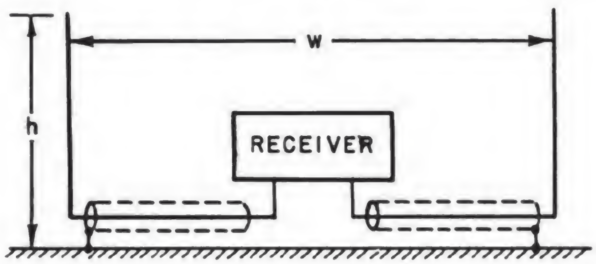
Figure 18-10.—Simplified block diagram of an automatic-bearing-indicator unit.



25.109
Figure 18-11.—Shielded U-Adcock antenna.

a tandem, or two-stage, goniometer with a common rotor shaft is used. The output of the N-E-S-W array is fed into one stage of the goniometer and the output of the NE-SE-SW-NW array is fed into the second stage of the goniometer. The stator windings are so positioned that the rotor null position for an incoming wave is the same for both stages, thereby retaining the desired figure-of-eight response. The octantal error voltages, equal in magnitude for both arrays, are connected in series opposition in the goniometer rotor, thereby cancelling all octantal error in the output.

The signal nulls are used for determining the direction of arrival of an incoming radio wave. Since there are two nulls, 180° apart, there is a 180° uncertainty, or ambiguity, as to the true bearing of the transmitter. Sense, or determination of absolute direction, is obtained by combining the ouput of a vertical monopole located in the geometric center of the array with the output of the U-Adcock system in the manner described for sense determination in the loop and Adcock antenna systems. The antenna arrays of the AN/GRD-6 system, therefore, consist of nine elements; eight are used for line-of-bearing determination, and the ninth for sense determination. (See figures 18-17 and 18-18.)

CIRCULARLY DISPOSED ANTENNA ARRAY SYSTEM

The circularly disposed antenna array (CDAA) system is a more recent development than any of the antenna systems previously discussed. It has been used primarily in the v-h-f and u-h-f bands, and is now being adapted for use in the h-f band. The CDAA system (also known as the Wullenweber system) has some gain characteristics which make it much more desirable than any other systems used for direction finding. These gain characteristics are particularly greater than those of previously designed systems for use in the h-f band. The reason for the advantage in gain will be pointed out shortly.

The CDAA consists of a group of omnidirectional antennas symmetrically spaced about the periphery of a circular reflector screen. The location of each antenna with respect to the screen and to the adjacent antennas is so designed that, by the use of a suitable antenna output scanning system, the antenna array provides high, unidirectional gain in all directions of azimuth. Figure 18-19 shows two concentric CDAAs—the outer one a high band array and the inner one a low band array. The desired signal is obtained by scanning the outputs of the antennas, around the circle. The output of the scanning system is greatest when it sweeps through the sector having high forward gain in the direction of a target transmitter. The scanning procedure results in sweeping the horizon with a direction finding beam, analogous to sweeping the horizon with a spotlight through a continuous arc of 360°.

The output of the goniometer (scanning device) at any angular position is actually the output of a monopole array—the combination of several of the monopole elements—rather than the output of a single monopole element. The resultant response will have a high forward gain (considerably greater than one) when compared to a monopole of the same dimensions as the individual antennas of the system. The output signal developed by loop and Adcock antennas, however, is actually the difference in signals of two monopole elements—the vertical components

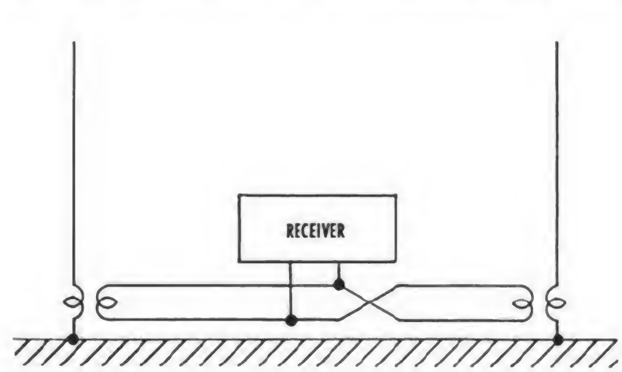


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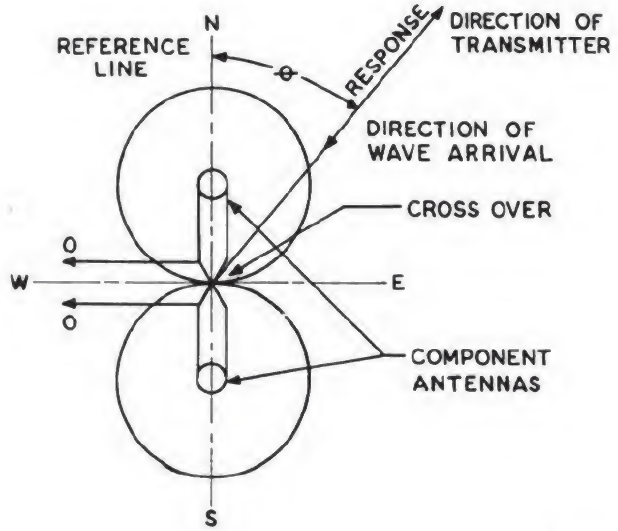
Figure 18-12.—Coupled Adcock Antenna.



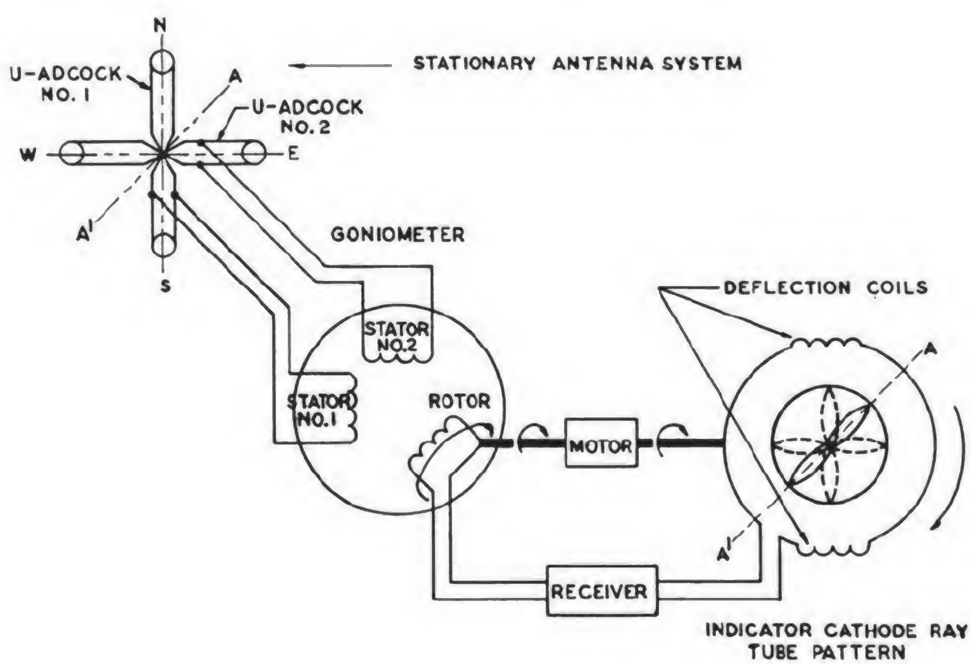
25.111

Figure 18-13.—U-Adcock antenna polar response diagram.

of the antenna. This means that the directional gain of a loop or Adcock antenna is small (much less than one) when compared to a reference monopole of the same dimensions as the vertical elements. Therefore, the CDAA has a very large increase in gain over the loop and Adcock antennas. Bearings may be obtained on incoming waves of much weaker strength and poorer quality when using the CDAA than when using loop or Adcock antennas, thereby allowing DF more distant from the DF site.

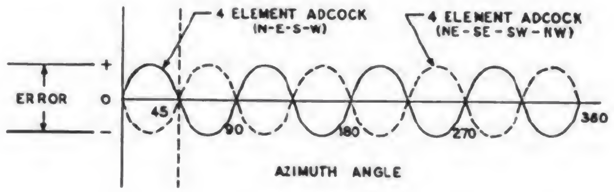
ROTATING ANTENNAS

In the u-h-f band and above, high gain unidirectional arrays can be constructed which are small in size, making it practical for direction finders operating at the higher frequencies to use some sort of rotating antenna which has a unidirectional pattern. To determine a true line of bearing to a transmitter, it is then necessary only to note which direction the array is pointed when the signal is received. Of course, in practical systems this is done automatically by



25.112

Figure 18-14.—Stationary antenna, goniometer and tube pattern diagram.



25.113
Figure 18-15.—Error cancellation.

synchronizing the indicator display of the received signal with the drive system which rotates the antenna.

DF RECEIVERS

COMPARISON WITH COMMUNICATION RECEIVERS

The outputs of loop and Adcock antennas are small compared to the average signal received from a communication antenna. Therefore, direction-finding receivers designed for use with these antenna systems must, in general, have higher sensitivity than the ordinary communications receivers. Because of the higher sensitivity requirement, the direction-finding receiver must be designed to obtain a low noise figure. Such receivers include shielding and filtering and may include noise-limiting and noise suppression circuits. However, since the principle of radio direction finding depends on measurement of changes in signal strength, automatic volume control cannot be used.

DESIGN CONSIDERATIONS

As is true for all receivers, the selectivity of direction-finding receivers must be sharp enough to suppress adjacent signals but broad enough to pass all frequencies included in the desired transmission. Navy DF receivers are usually of the superheterodyne type.

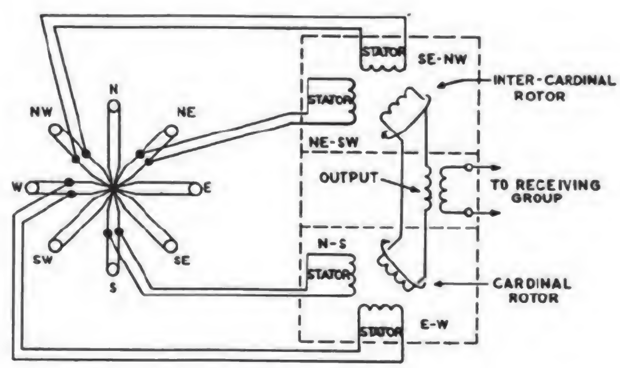
Since DF depends on the rotation of the antenna, either physically or electrically, the signal level varies from essentially zero at the null points to very large values at the maximum points. This variation requires that the amplifiers used in the receiver be designed to handle the larger signals without overload and that the detection circuits be designed to obtain linear detection signals of all levels. The requirement of linear detection is especailly hard to accomplish at the low signal levels. If linear detection of low level signals is not attained, errors are produced at the critical null points.

DF INDICATORS

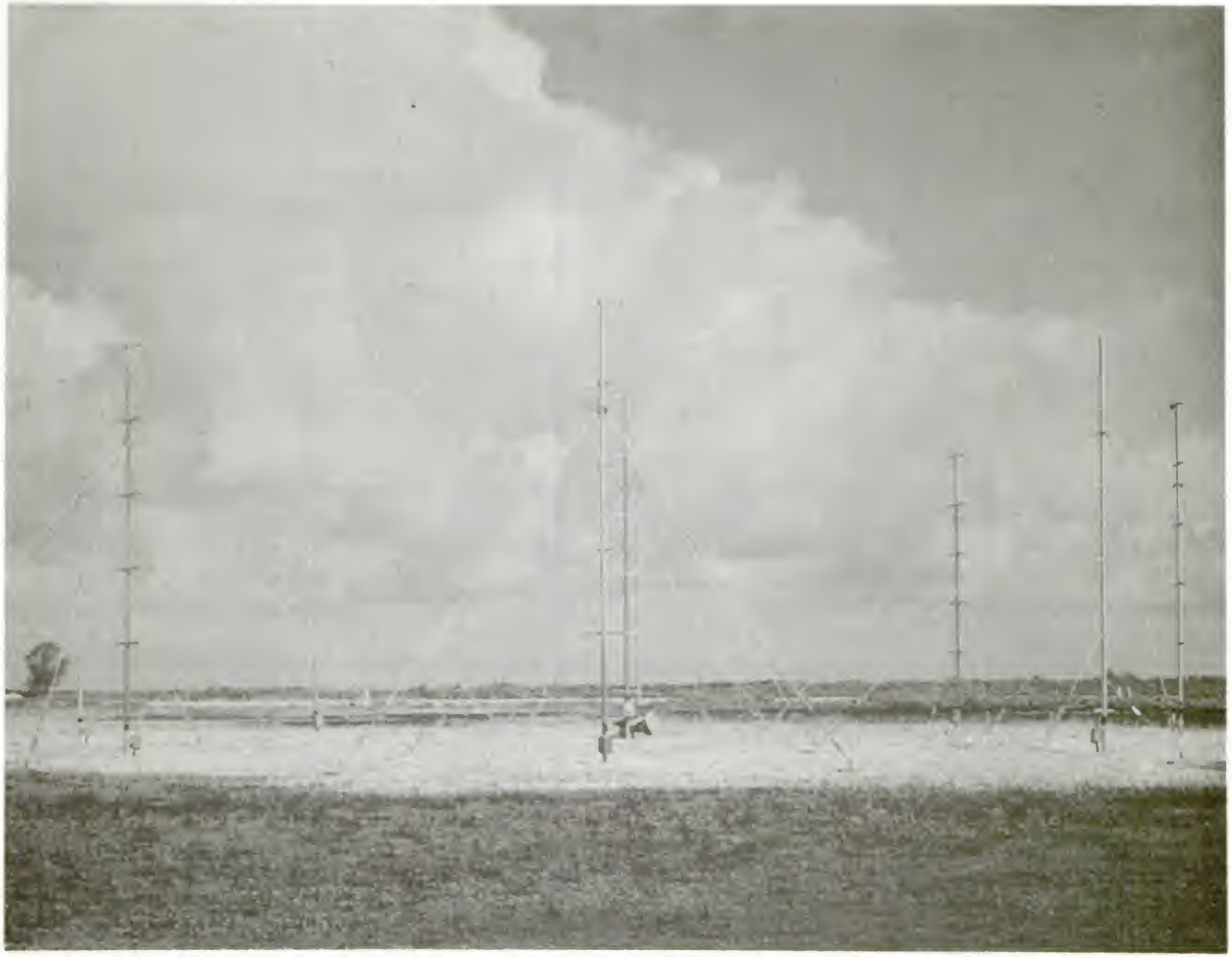
Direction-finding indicators fall into three general classes: aural (headphones or speaker), visual (meter needle or cathode-ray tube), and automatic (suitable for use with homing devices). However, for our purposes, only the cathode-ray tube indicator is of importance. There are two basic types of cathode-ray tube direction-finder displays in common use. Each of these types will be discussed briefly. Both types of cathode-ray displays generally employ magnetic deflection, with a deflection yoke which rotates about the neck of the cathode-ray tube.

In the first type of display, the yoke is energized in proportion to the strength of the received signal. When no signal is being received, the spot rests at the center of the screen, as shown in figure 18-20A. When a signal is received, the pattern which results in a polar plot of the directivity pattern of the DF antenna. The bearing of the signal is determined by the direction of maximum deflection of the spot, as shown in figure 18-20B. This type of display is ordinarily used for direction finders which employ rotating unidirectional antennas.

The second type of direction-finding display is ordinarily used for direction finders which use antenna systems having figure-of-eight response patterns. It is the type of display with which the CT will probably become most familiar. In this display, the yoke is normally



25.114
Figure 18-16.—Simplified tandem goniometer.



25.115

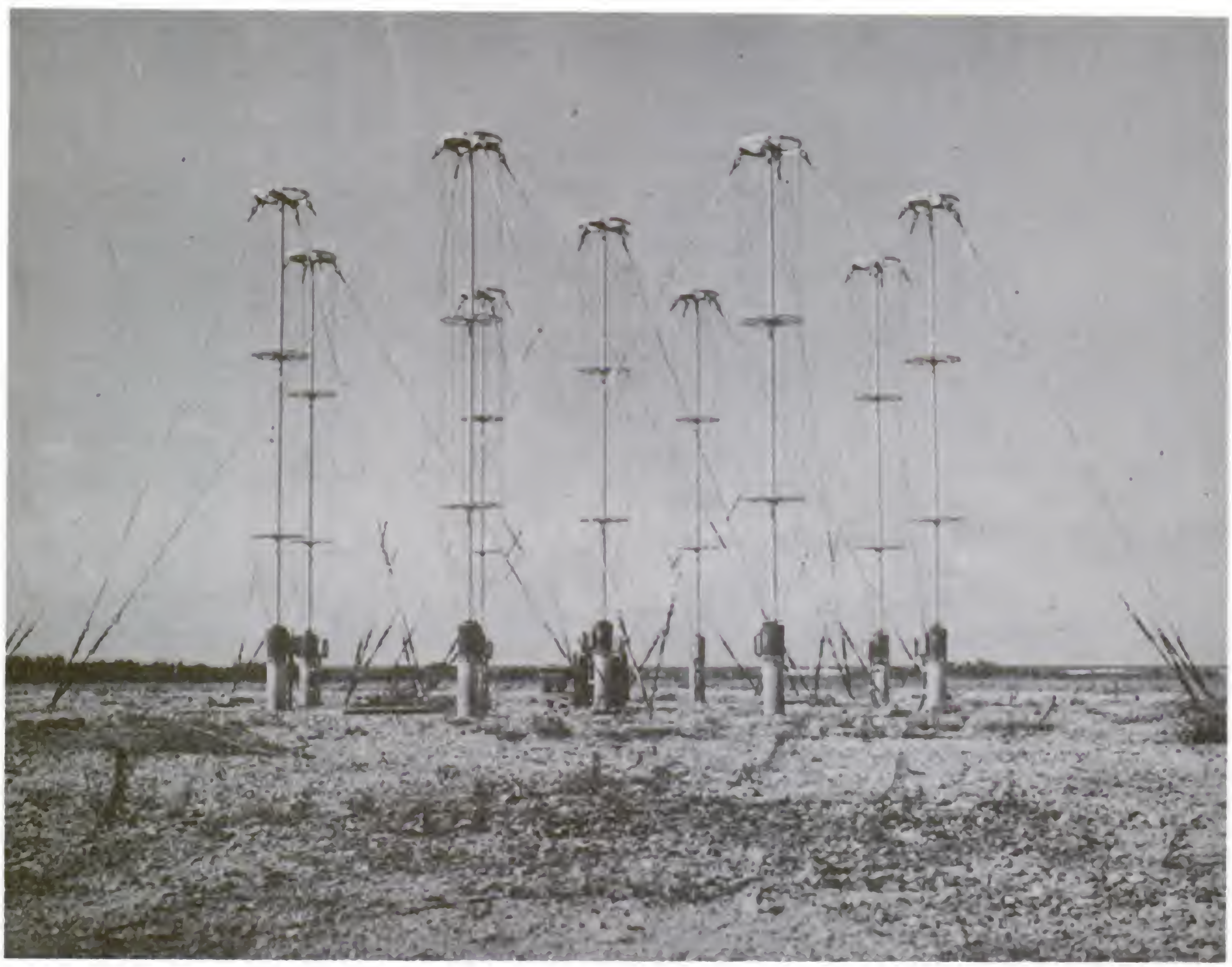
Figure 18-17.—AN/GRD-6 low band array.

energized; thus when no signal is received the spot traces a circle. When a signal is received, the spot is deflected toward the center of the screen. A block diagram of an automatic-bearing-indicator which incorporates this display is shown in figure 18-21. The goniometer rotor and the magnetic deflection coils of the cathode-ray tube are mechanically coupled together on one shaft which is rotated by a motor. For each revolution of the goniometer, the oscilloscope spot is moved once around the oscilloscope screen. The pattern on the cathode-ray tube is the output of the goniometer after amplification, detection, and inversion. The pattern is inverted so that a zero signal, such as the nulls of the figure-of-eight pattern, moves the oscilloscope pattern to the edge of the screen, and a large signal moves the spot toward the center. This action inverts the pattern from the dotted line to the solid line in figure 18-22. After inversion, the null points become the tips of the indicator pattern and the line of bearing is more easily read.

After the bearing pattern is obtained, the crossed loops of the system are combined with the sense antenna to give a cardioid pattern as shown by the dotted line in figure 18-22. The cardioid, which is inverted in the same manner as the propeller-shaped bearing pattern, is shown by the solid line in figure 18-23. It is

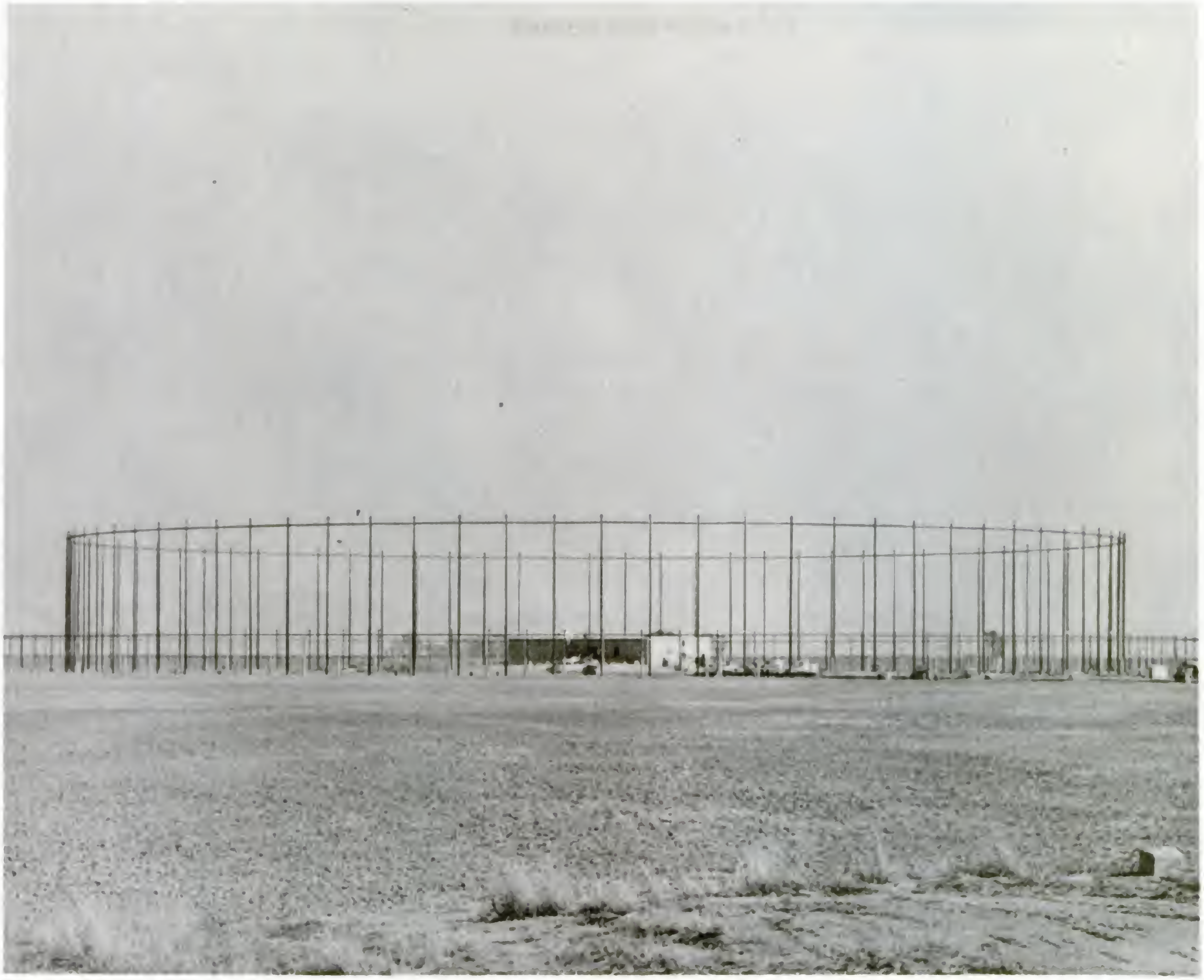
convenient to rotate the sense pattern by 90° on the oscilloscope screen so that it is symmetrical with the bearing pattern. Rotation is accomplished automatically, in the system illustrated in figure 18-21, by switching the output of the deflection amplifier to sense deflection coils, which are advanced 90° from the bearing deflection coils. At the same time, the sense antenna is switched into the circuit. After being rotated 90°, the sense pattern appears on the screen as in figure 18-24.

In operation, the bearing pattern is obtained first. The operator then rotates a cursor on the face of the oscilloscope so that it points in the direction of one of the tips of the bearing pattern. The direction he points the cursor is the direction from which he assumes the signal to be coming. Next, the sense button is pressed. If the sense pattern falls on the "tail end" of the cursor, he has assumed the correction direction; if the sense pattern falls in the direction the cursor is pointed, the operator knows that the true bearing is 180° from the assumed direction. Figure 18-25 illustrates the bearing and sense patterns for a transmitter that has a direct bearing on 000. The sense pattern is dotted to emphasize that the two patterns are not obtained simultaneously.



25.116

Figure 18-18.—AN/GRD-6 high band array.



25.117
Figure 18-19.—Circularly Disposed Antenna Array (Wullenweber System).

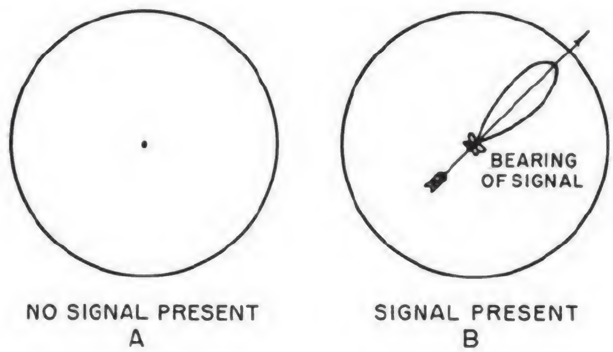
DIRECTION FINDER CENTRAL, AN/GRD-6

This section includes a description of an HFDF system. The AN/GRD-6 is used as an example to illustrate the equipments which are included in a direction finding installation. Because of the complexity of the equipments involved, this discussion is limited to a general, functional description. When a CT M is required to perform maintenance on the equipment, he will need to study carefully the instruction manual.

The AN/GRD-6 is a direction finder radio receiving system which automatically furnishes azimuth indications of radio signals within the frequency range of 2 to 32 mc.

BASIC SYSTEM OPERATION

In the AN/GRD-6 system, the direction of arrival of the signal is measured by utilizing the characteristic response of U-Adcock antennas. The actual sense of direction of the sources of r-f radiation is determined from a combined response of the U-Adcock antennas and an omnidirectional monopole "sense" antenna. The resultant antenna signals are automatically converted into visual indications by the associated operating equipment.



25.119
Figure 18-20.—DF presentations on a cathode-ray tube.

The operator then performs some simple operations to interpret and evaluate the visual indication. These operations, in general terms, are:

1. Lining up a cursor with the visual pattern on the indicator.
2. Determining the "sense"
3. Evaluating the quality (reliability) of the bearing.

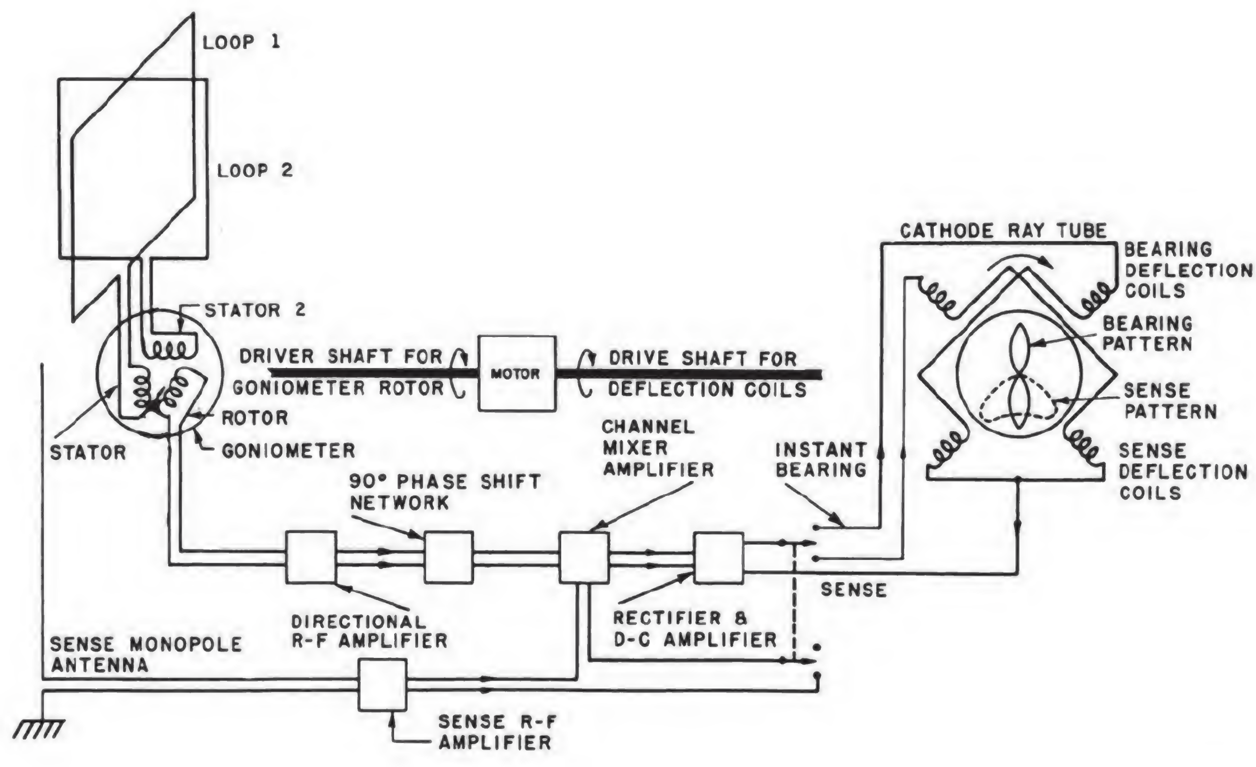
Actual operator procedure includes the rotation of an alidade ring and pushing buttons on a switchbox. (Figure 18-26.)

When the operator has performed the operations in a prescribed manner, the azimuth and quality information is applied to a coder that converts the information into coded teletype information which is transmitted to the central plotting agency.

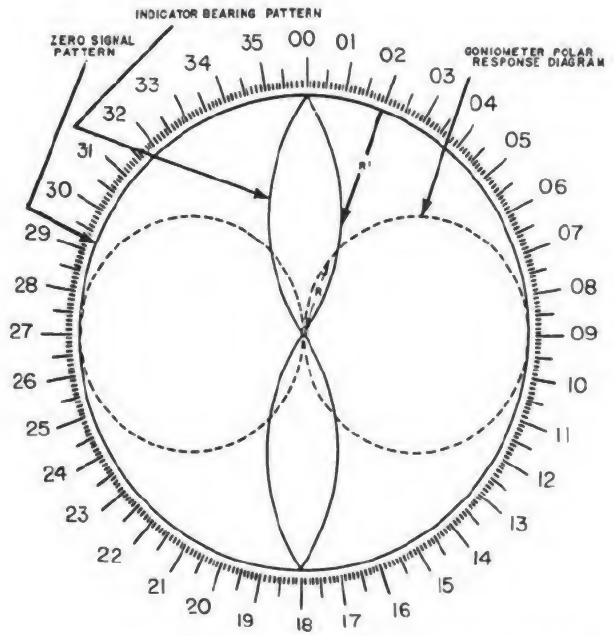
The AN/GRD-6 system covers the frequency band of 2 to 32 mc in two band divisions, 2 to 8 mc (low band) and 8 to 32 mc (high band). The equipment groups of the system are also divided into these two divisions, each division requiring an operator. Figure 18-27 shows a block diagram of the basic AN/GRD-6 system.

MAJOR SYSTEM GROUPS

The AN/GRD-6 system has three equipment groups that correspond directly to the three



25.120
Figure 18-21.—Block diagram of an automatic-bearing-indicator system.



25.121
Figure 18-22.—Figure-of-eight pattern inverted to give the indicator bearing pattern.

basic components of any radio direction finding system: a directional antenna array, a radio receiver, and a bearing indicator. In addition, the AN/GRD-6 system has a bearing coder group. As each of the groups is discussed, refer to figure 18-28 to associate the group's functional relationship to the system.

ANTENNA GROUP

The Antenna Group of the AN/GRD-6 system consists of two antenna arrays, one for low band (2 to 8 mc) and one for high band (8 to 32 mc) operations. The antenna elements used for both arrays are vertical monopoles forming U-Adcock antennas. The low-band elements are terminated, folder monopoles. The high-band elements are broad-band sleeve or cage-type antennas. To eliminate "loop effect," each of the individual low-band antenna elements is arranged with symmetrically disposed down leads (figure 18-29) which cause currents to be equal and opposite, thus eliminating the loop effect of the down leads while still allowing the element to operate in the normal manner.

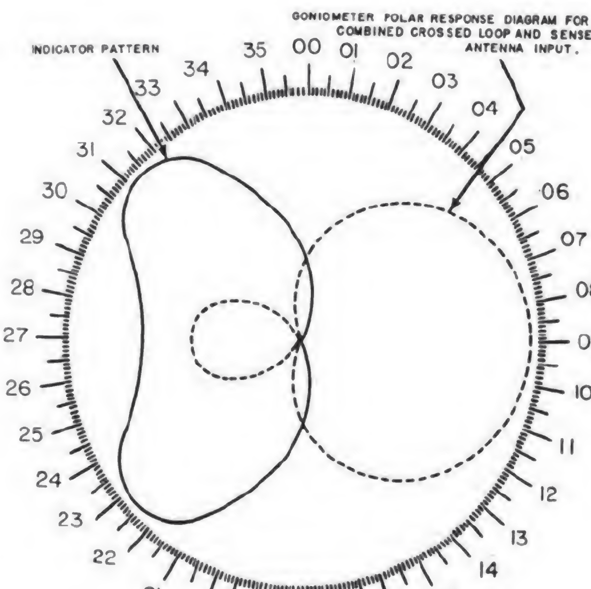
The other component of the antenna array used with the AN/GRD-6 is a pulse generator which generates pulses at a frequency equal to the goniometer rotor speed. These pulses are used for synchronization of the drive system of the deflection coils in the cathode-ray indicator to the speed of rotation of the goniometer rotor.

RECEIVING GROUP

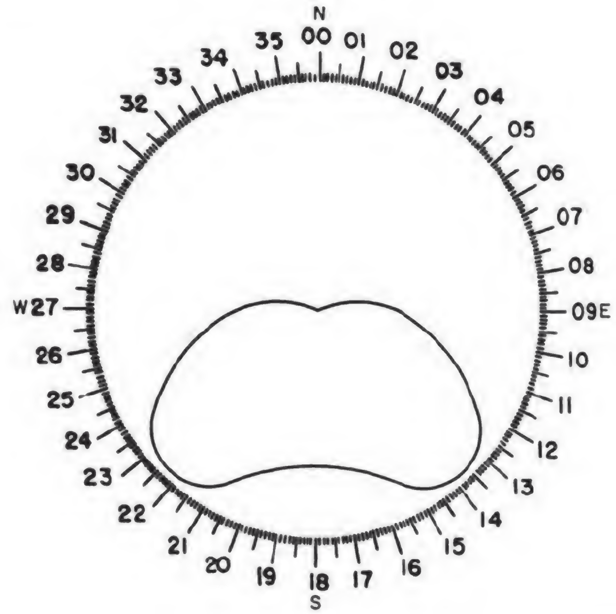
The receiving group for each band is made up of a tunable receiver (the R-665/GRD-6) and a power supply. The receiver r-f tuning is divided into 4 bands. Band 1, 2 to 4 mc; band 2, 4 to 8 mc; band 3, 8 to 16 mc; and band 4, 16-32 mc.

BEARING INDICATOR GROUPS

The bearing indicator groups are ordinary magnetic deflection cathode-ray tube displays with circular sweeps. The sweep speed is synchronized with the goniometer rotor speed. The deflection is adjusted in such a manner that for



25.122
Figure 18-23.—Cardioid pattern of combined loop and monopole antennas, and inverted indicator pattern.



25.123
Figure 18-24.—Sense pattern after a rotation of 90° on indicator screen.

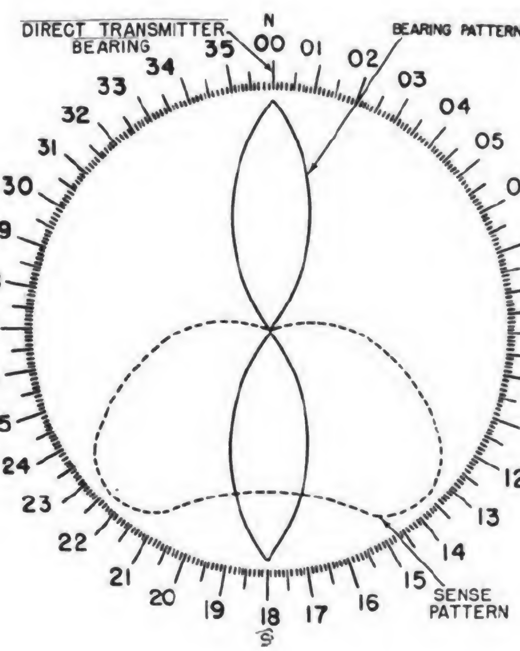
no signal the spot is traveling around the edge of the screen; and when the signal is maximum, the spot is at the center of the screen. With this arrangement, the familiar propeller pattern develops from the Adcock antenna system response.

Bearing Coder Group

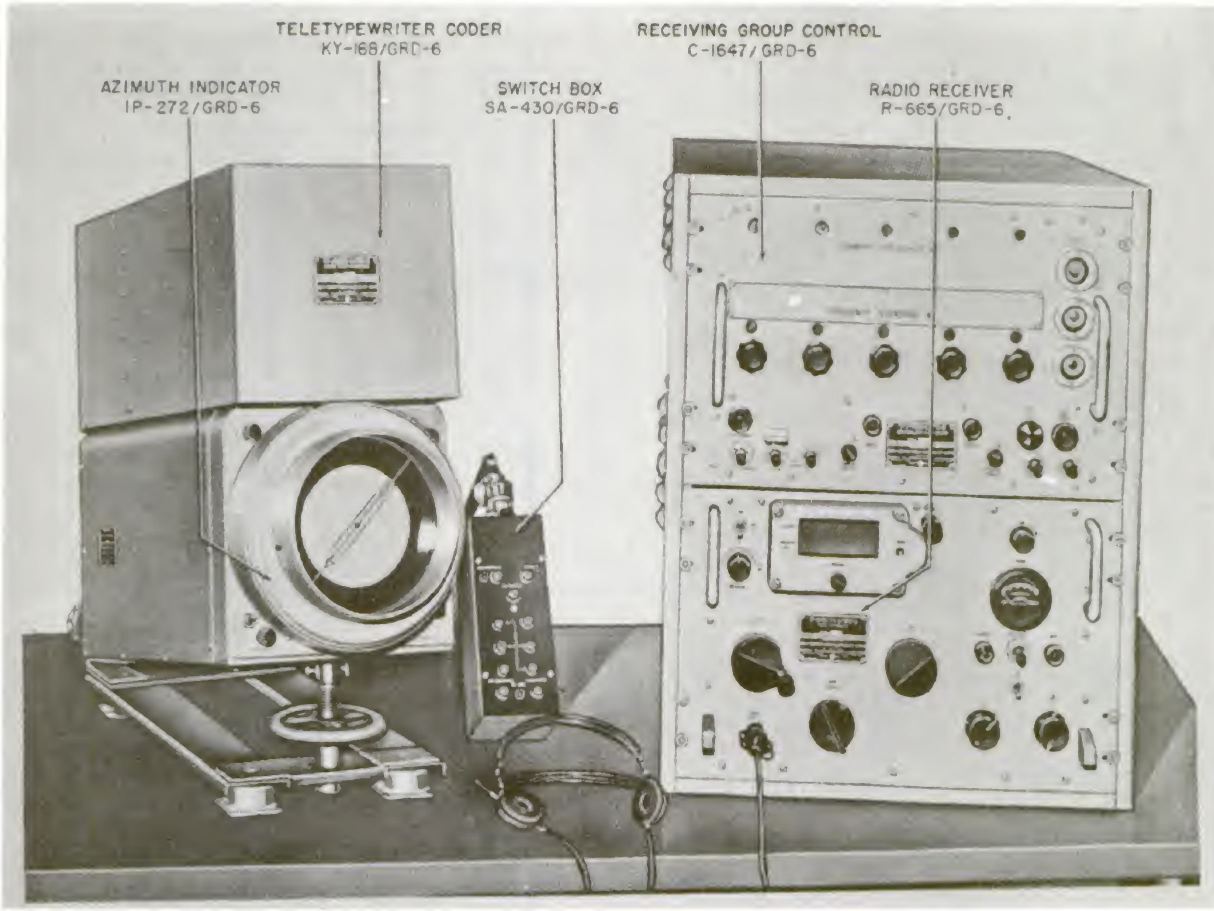
Visual bearing azimuth indications and relative bearing information as to quality and sense determination of the bearing are observed and interpreted by the operator. This bearing data is then translated into teletype code and automatically transmitted to recording equipment by the Bearing Coder Group.

Bearing information, as observed by the operator, is set up by rotation of the alidade ring on the indicator to correspond with the bearing of the signal. This operation rotates coded disks within the alidade reader which are used to set up the resultant teletype code. After the alidade ring has been positioned, the operator pushes the sense switch on the indicator panel and notes whether the alidade pointer is pointed in the correct direction. Depending on the sense, he pushes one of two buttons (RECIPROCAL or DIRECT) on the bearing coder switch box. He next pushes one of four pushbuttons which correspond to the operator's evaluation of the quality of the determined bearing. Upon pushing the QUALITY pushbutton, the following cycle occurs:

1. A relay in the bearing sender corresponding to the quality pushbutton depressed locks up.
2. The relay contacts provide ground to the five-wire quality circuit according to the teletype code for the quality letter selected.
3. At the same time, a magnetic brake assembly stops rotation of the bearing translator (alidade reader) shaft and the alidade.
4. The alidade reader motor starts to rotate a multi-track cam against which followers are held by spring pressure.
5. The followers drop in order and allow the half-degree, the degree, and the one set of the tens and hundreds degree fingers to successively engage the slotted discs in the alidade reader.
6. The teletype distributor starts to rotate and sends out bearing information until the bearing, derived from open and closed circuits on switches associated with the half, units,



25.124
Figure 18-25.—Bearing and sense patterns.



34.36

Figure 18-26.—Typical operating position (AN/GRD-6)

tens, and hundreds fingers, and the quality letter derived from the quality relay has been sent out.

This concludes the discussion of the AN/GRD-6. Because of the complexity of the equipment, it has been impossible to outline the details of electrical and mechanical operation. When corrective maintenance is required on the AN/GRD-6, the procedures outlined in chapter 7 of the instruction manual should be carefully studied and followed. Chapter 7 includes charts to assist the technician in localizing the faulty portion of the equipment and charts to assist in analyzing the probably cause of the fault. The procedures for routine preventive maintenance, as outlined in chapter 6 of the instruction manual, should be performed at least as frequently as called for in the manual. In addition to assuring proper performance of the equipment, the routine maintenance checks are valuable to the maintenance technician in that they will familiarize him with the equipment—and familiarization is a prerequisite to competent performance of corrective maintenance.

DIRECTION FINDER ERRORS AND CALIBRATION

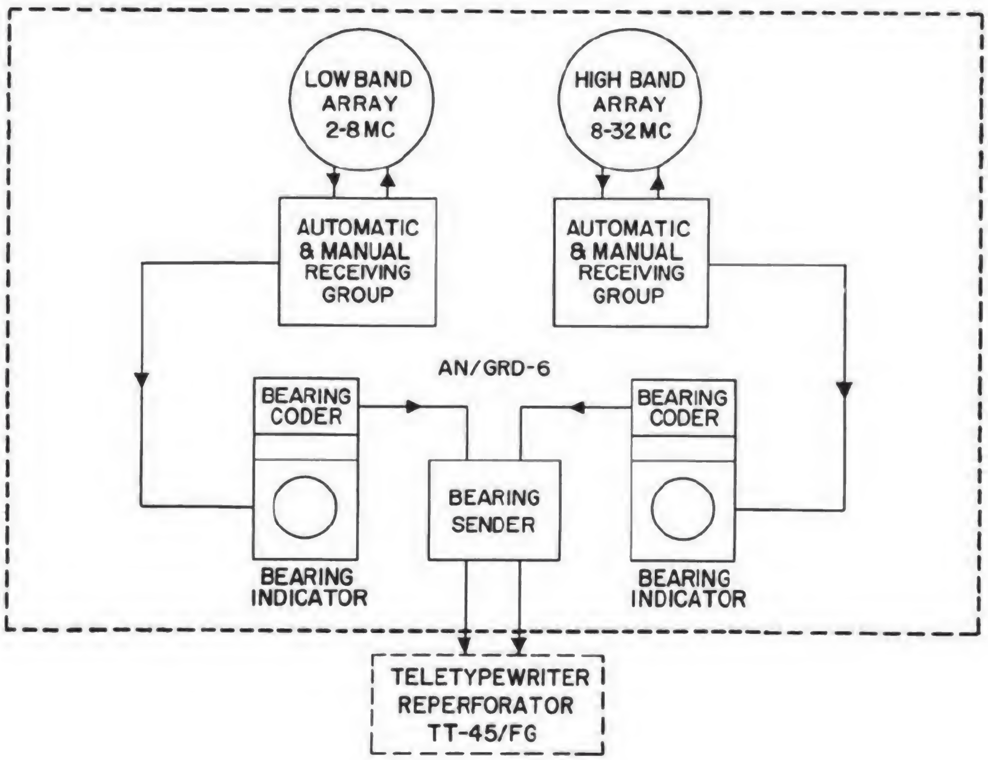
Some of the errors of direction finders have already been discussed; for example, loop effects. If the direction finder antenna system has horizontal components, polarization error or night effect will cause erroneous DF bearings. The susceptibility of a DF system to

polarization errors is a result of its design; little can be done to compensate for these errors. Most systems which incorporate loop antennas are designed for l-f and m-f direction finding. These errors will be most likely to occur when operating at the higher frequencies of the system's frequency range since some of the energy may then arrive by means of the sky wave.

Direction finders used in the h-f band are also prone to some errors which cannot be compensated for. These errors are usually due to some characteristic of the propagation path between transmitter and DF. For example, if the DF is located within the skip zone of an HF transmission, the equipment may still be able to pick up a weak signal. However, the signal will not appear to come from any one direction, as noted by wandering and unsteady displays, because the energy that actually does arrive because of refraction will be descending from a nearly vertical direction onto the antennas. Thus, the angle of incidence in the horizontal plane is extremely difficult to determine.

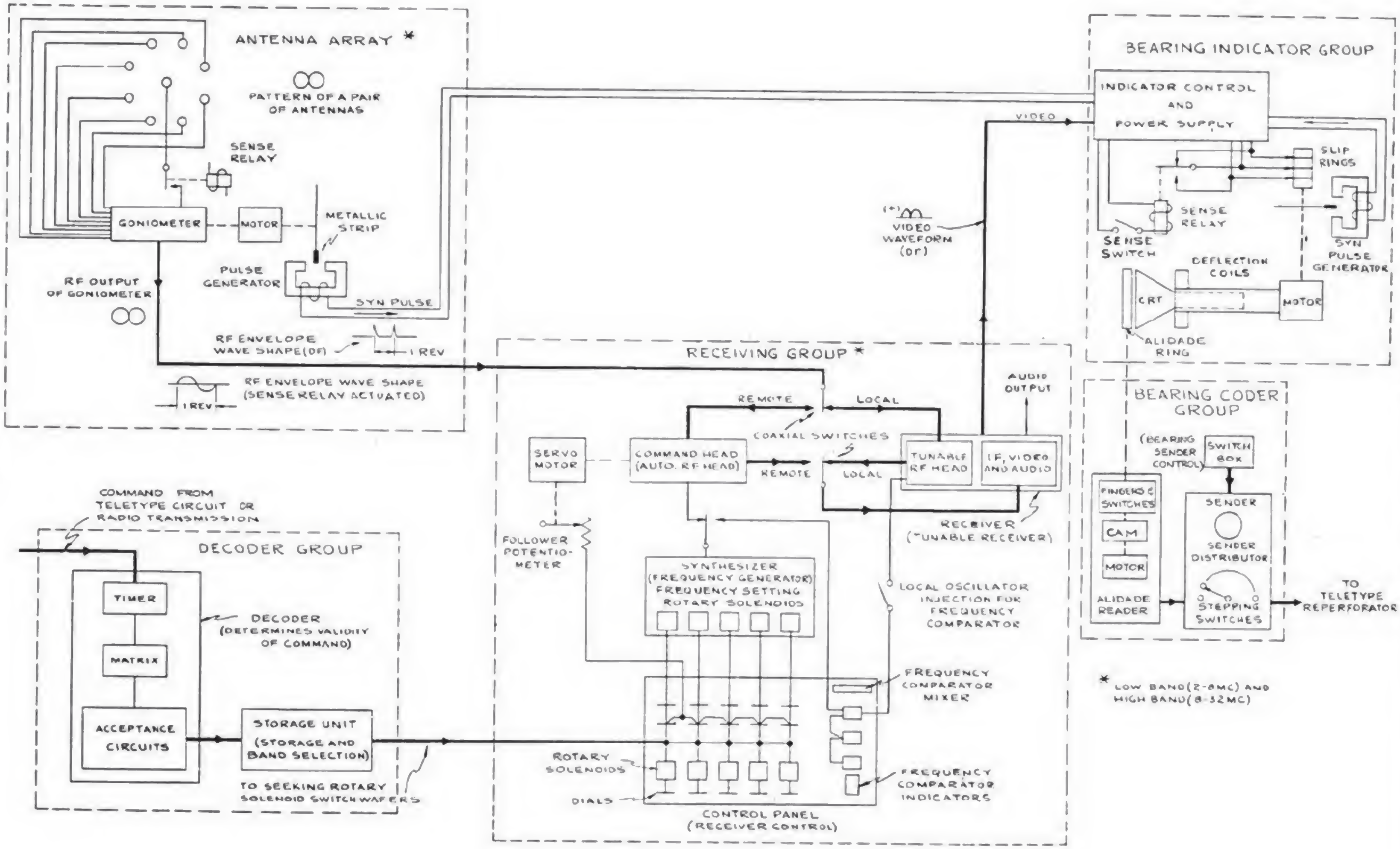
Unusual conditions along the path of a radio wave may cause re-radiation of signals from various points along the path. These points act as small transmitters and give rise to an effect known as "scattering." The effect of scattering can be considered analogous to the effect of particles in the path of a searchlight beam. You have probably seen a searchlight beam directed upward into the atmosphere even though you were several miles from the searchlight or the beam. The reason you were able to see the beam is that minute particles in the path of the light reflected a portion of the light out of the beam. If the atmosphere were perfectly clear, you would be unable to see the beam unless you were actually within it.

A similar phenomenon occurs with a radio wave. Small charged areas in the path of the wave tend to reflect or "scatter" a portion of



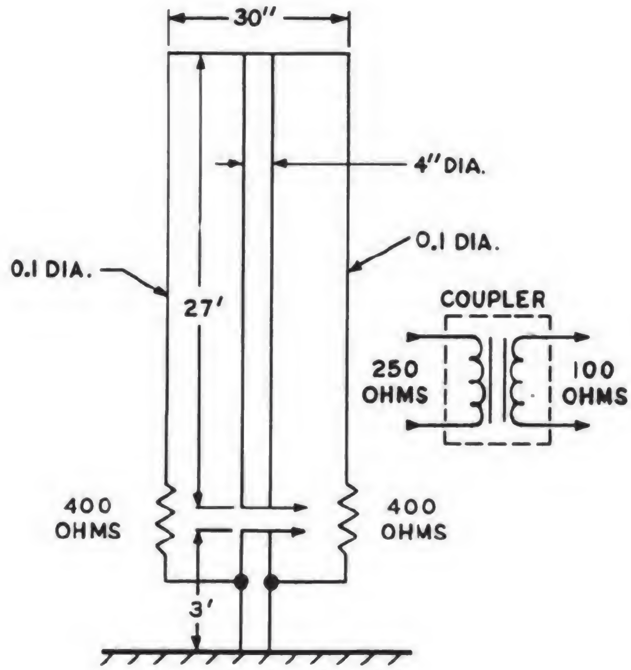
25.125

Figure 18-27.—Direction finder central AN/GRD-6, function block diagram.



25.126

Figure 18-28.—Direction finder central AN/GRD-6, simplified over all block diagram.



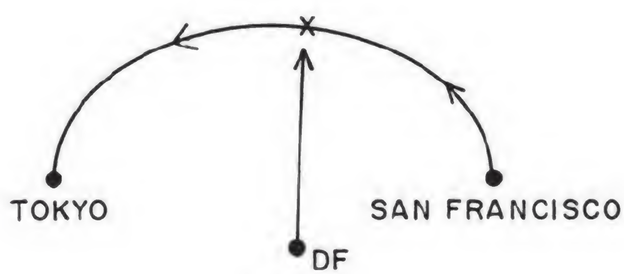
25.127
Figure 18-29.—Terminated folded monopole.

the wave from its normal path. A dense "charge cloud," such as might be created by a meteor or comet trail in the path of a radio wave, would reflect a large amount of energy. Reception due to scattering produces many confusing effects on a DF. The scatter points may cause a DF within the skip zone or far beyond the normal range of a signal to receive a strong signal. The DF bearing obtained will be on the scatter point, not on the transmitting station, and the scatter point may be far removed from the great circle path between the DF and the original transmitter. Thus, it is possible to obtain bearings which are up to 180° in error because of the effects of scattering. Figure 18-30 illustrates the effects of scatter points on DF. Fortunately, at most times when scattering causes reception within the skip zones, or causes distortion of signals received within the ordinary area of reception, the display tends to wander, thus giving the operator warning as to the reliability of the bearing.

A source of error in all DF systems is caused by locally re-radiated signals which may be caused by the reflecting effect of wires, masts, buildings, trees, etc. in the vicinity of the DF antenna. The effect of re-radiated fields on a DF antenna is known as the quadrature effect because it causes an induced voltage component in the DF antenna which is a quadrature (90°) with the voltage induced by the true signal. The result of re-radiation of the r-f wave is to deviate, or displace, the null of the DF antenna response. Direction finders which are located in confined areas, such as on board ships, are almost certain to have deviation of their nulls because it is impossible to completely isolate the DF antenna system from other antennas, masts, etc. Therefore, it is necessary for such DF systems to make experimental measurements of direction to radio transmitters of known bearings. The DF bearings obtained on these stations of known bearings are compared with the true bearings to plot calibration curves, or deviation curves, for the system. These curves are consulted to give the correction which must be applied to observed bearings in order to obtain the correct bearings to radio transmitters.

Direction finders located at fixed sites are generally located in remote areas where the effect of local re-radiation can be removed or at least minimized. In order to ensure the accurate performance of a fixed DF, however, local error tests are conducted periodically in accordance with the instruction book for the particular system. These tests are normally conducted semi-annually or after any major change in equipment or site area.

The general procedure for local error calibration of an HF direction finder is as follows. A small target transmitter is accurately positioned in azimuth (by the use of a transit) at a prescribed distance from the DF antenna. For each position of the target transmitter, DF



25.128
Figure 18-30.—Reception from scatter point.

bearings are taken at a series of frequency check points. While the bearings are being taken, extreme care must be taken that no persons or metallic tools, tapes, wires, etc. are in the vicinity of the DF array or the transmitter. Any such items will tend to re-radiate the signal and cause an error in the observed bearing. This procedure is repeated at prescribed intervals of azimuth. (For the AN/GRD-6 the intervals are every 10°.) Errors noted by this procedure (for each frequency) are usually plotted versus azimuth and compared with the error curves obtained from the previous calibration checks. The maximum error at any frequency and azimuth check point should be no greater than plus or minus 3 degrees.

It should be noted that the local error test just described is valuable in determining, insofar as possible, the performance of a DF installation. The error curves obtained are not, however, used as correction curves on the bearings of actual targets. In most instances the error curves obtained in the local error test would be quite different from the error curves which would result from long-range signals. Because of the extreme difficulty (or impossibility) of performing a long-range calibration test, operations personnel have a prescribed method for determining the accuracy of a given DF station. Daily bearing checks are observed on stations of known azimuth and frequency to ensure that normal operating conditions exist. Any radical departure from normal operation should be easily determined by the operator. In addition to the local daily bearing checks, the central plotting agency of a DF net ordinarily requires the stations of the net to take bearings on known fixed targets. The bearings obtained by the individual stations are recorded and tabulated. A statistical analysis of the bearings is made to provide a measure of performance for evaluation and comparison of direction finders. Of the various quantities which can be obtained by statistical analysis, the systematic error (arithmetic mean error) and the standard deviation are the most commonly used. The systematic error is an average value, which balances out both accurate and inaccurate readings, both positive and negative, and furnishes a measure of the performance of the direction finder as an overall system. The standard deviation is a measure of the spread of the bearings about the systematic error. A systematic error which is as small as possible is desired as an indication of the absence of site and equipment error. Likewise, a small standard deviation is desirable since it indicates that the spread of the bearings about the systematic error is narrow and the bearings are consistent.

MAPS USED IN DF PLOTTING

Radio waves travel in great circle paths along the earth's surface. For DF plotting purposes, it is desirable that these great circle paths be shown as straight lines on a map to simplify the problem of plotting. A special map projection having this quality has been designed, the Gnomonic projection, but although great circles appear as straight lines, distances and shapes must be distorted, and hence the maps are of use only for DF and navigational purposes. Other maps which can be used for DF plotting are the Lambert conformal conic projection and the Mercator projection. The Mercator projection can be used for fairly accurate results up to a distance of 50 miles without correction and from 50 to 200 miles with correction for angular distortion, but should not be used at distances greater than 200 miles because of extreme distortions which result. The location of a transmitter can be determined by plotting several intersecting bearings on a map; this process is sometimes called radio position finding. The term "cut" designates one station's bearing on a target and a "fix" is the intersection of two or more cuts.

CHAPTER 19

MAGNETIC AMPLIFIERS

Electronics personnel usually associate amplification of voltage or power with vacuum and gas tubes. However, several devices accomplish amplification without the use of tubes. One of these, the magnetic amplifier, has been in use here and abroad for many years. The magnetic amplifier has certain advantages over other types of amplifiers. The advantages include (1) high efficiency (90%), (2) reliability (long life, freedom from maintenance, reduction of spare parts inventory), (3) ruggedness (shock and vibration resistance, overload capability, freedom from the effects of moisture), (4) stability, and (5) no warmup time. The magnetic amplifier has no moving parts and can be hermetically sealed within a case similar to the conventional dry-type transformer.

The magnetic amplifier has a few disadvantages. For example, it cannot handle low-level signals (except for special applications), it is not useful at high frequencies, it has a time delay associated with magnetic effects, and the output waveform is not an exact reproduction of the input waveform.

The term "amplification," in general, refers to the process of increasing the amplitude of voltage, current, or power. The term "amplification factor" is the ratio of output to input. The input is a signal that controls the amount of available power delivered to the output. Thus, tubes are really "valves" that permit a controlled amount of power to be delivered to a load. A difference in high-vacuum tubes and gas tubes is that the signal on the grid of a vacuum tube always has control of the output signal—that is, the valve can open and close partially, whereas in gas tubes the grid loses control when the gas ionizes, so that the valve is either completely open or closed. For this reason thyratrons frequently are supplied with a-c plate voltage—the valve shuts off automatically when the plate voltage cycles to zero. It will be seen that the magnetic amplifier is similar in action to a thyratron.

PRINCIPLES

SATURABLE REACTORS

In older references the magnetic amplifier is called a saturable reactor. Other references can be found in which the magnetic amplifier is called a transducer. However, "magnetic amplifier" is the term used in most modern references to describe the device that uses saturable reactors to control a-c power.

A simple saturable reactor is a coil on a magnetic core. When current flows through the coil, lines of flux are produced which link the coil. When the current alternates, the lines of flux alternate, changing amplitude and direction with it. Instantaneous values of induced emf are proportional to the rate-of-change of current and the accompanying flux. This rate-of-change is maximum when current and flux are zero; hence, the induced emf is 90° out of phase with the current. The induced emf opposes any change in current and lags the current by 90°. As the induced emf (counter voltage) is 180° out of phase with the voltage applied across an inductor of negligible losses, and constitutes the only opposition to current flow therein, the current lags the applied voltage by 90°.

Briefly reviewing some of the facts concerning saturation of a coil, it will be remembered that when current flows through a coil there is set up about the coil a magnetomotive force, the intensity of which depends upon the amount of current flowing through the coil. This force in a magnetic circuit may be compared to the voltage of an ordinary electric circuit.

$$I = \frac{E}{R} \text{ and}$$

$$\phi = \frac{F}{R}$$

The magnetomotive force sets up a flux about the coil, which is comparable to the current of an ordinary circuit and has a density which depends on the reluctance of the core of the coil. The core reluctance, which may be compared to the resistance of an electric circuit, has a value which depends on the material forming the core. The reluctance of an air core remains constant regardless of current. This results in an increase of flux density which is in proportion to the increase in both current and magnetomotive force. When a magnetic substance makes up the core of a coil, however, the reluctance is no longer constant, regardless of current. Instead, as a current begins to flow, the reluctance is very low and the flux is very high compared to that existing in an air-core coil under similar conditions. With an increase in current, the reluctance gradually increases and the rate-of-flux increase is reduced. After the current reaches a certain value, which depends on the core material used, the reluctance increases very rapidly until its value approaches that of air. At this value, any further increase in current will produce no appreciable increase in flux. This condition is known as saturation.

HYSTERESIS LOOP

Hysteresis loops in which magnetizing force H is plotted against flux density B are shown in figure 19-1. The loop shown in figure 19-1A represents the cycle of magnetization for an inductor with a core material of standard nickel-iron alloy. The loop shown in figure 19-1B, represents the cycle of magnetization for an inductor having a core of specially treated nickel-iron alloy. This core material is known as Permenorm 5000-Z and is designed to produce a rectangular hysteresis loop.

A core such Permenorm makes a much more efficient saturable reactor than one like that in figure 19-1A. One reason for this is that the Permenorm core develops much higher flux densities before saturating. This permits a greater range of power control from a core of a given size. Another reason is that the more sudden discontinuity at the "knee" of the Permenorm response curve results in an output wave shape that is more sinusoidal than that of standard material.

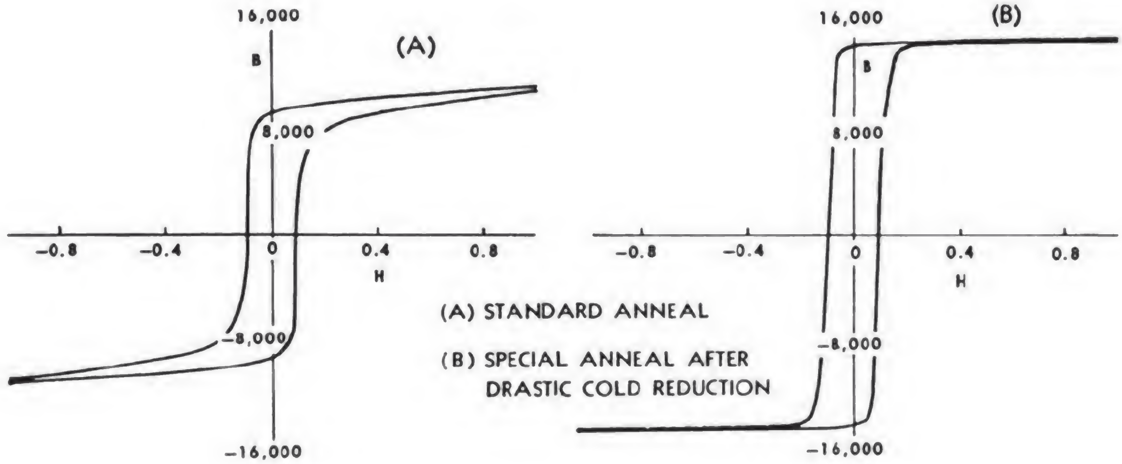
AMPLIFIER OPERATION

Consider the operation of the magnetic amplifier shown in figure 19-2. It consists of a two-winding saturable inductor, one winding of which is connected in series with a rectifier, the a-c source, and the load. This part of the amplifier is a half-wave, self-saturating circuit in which the inductor controls the time in the cycle when the high unsaturated impedance of its a-c winding is removed and current flows unimpeded through the load. The time is varied by introducing a small d-c control voltage across the d-c winding of the inductor. The circuit shown in figure 19-2A, is used to explain simply how the amplifier works. It is not a practical operating circuit because of the a-c voltage induced by transformer action in the d-c control circuit. For purposes of analysis assume that the impedance, Z, is added in series with the d-c control circuit to limit the a-c current to a negligible value.

The a-c and d-c windings on the inductor are assumed to have negligible resistance and the rectifier to act as a one-way valve with zero forward resistance and infinite backward resistance. The load resistance is assumed to be low in comparison to the high unsaturated impedance of the a-c winding. The inductor core material has a rectangular hysteresis loop like that shown in figure 19-2B.

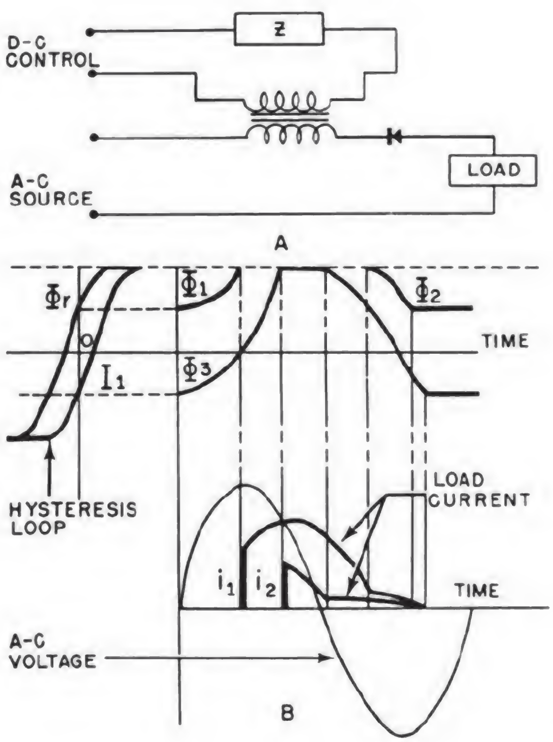
Consider first the cycle of operation when the control current is zero. The a-c voltage supplied across the load circuit is of sine waveform, as shown in the lower portion of figure 19-2B. Values of a-c winding current are plotted along the X axis with corresponding values of flux as ordinates to form the hysteresis loop shown in the upper left of figure 19-2B. As the current increases in a positive direction, the flux rises until it reaches saturation. This increasing flux is plotted against time in the upper portion of figure 19-2B, and is labelled $\phi 1$. Up to this time the load current is limited to a very small value due to the high unsaturated impedance of the a-c winding. At saturation this impedance drops to almost zero and the load current rises sharply as indicated at i_1 in the load current-time diagram of figure 19-2B. After this sudden increase, the load current has the same shape as the sine wavefore of applied voltage. The load current lags the applied voltage because of the remaining inductive reactance in the circuit.

As the voltage and current decrease, the flux ϕ_2 decreases in accordance with the variation along the upper branch of the hysteresis



1.291

Figure 19-1.—Hysteresis loops of two reactors.



1.292

Figure 19-2.—Magnetic amplifier. (A) Circuit; (B) Flux-current curves.

loop. When the load current reaches zero there is a residual flux ϕ_r in the core. The residual flux is not removed during the negative half cycle because the rectifier prevents the load current from reversing. Each half cycle the core flux rises from the residual value ϕ_r and in the interval preceding saturation limits the load current to almost zero. As seen in figure 19-2B, half of the first quarter cycle of applied voltage, there is no load current because of the high impedance of the unsaturated series inductor.

With control current in the d-c winding the value of residual flux may be changed. It depends on the magnitude and polarity of the d-c control voltage and current. Consider the effect on load current when a small negative control current I_1 is introduced into the d-c winding. This current establishes the flux ϕ_3 at the beginning of each positive half cycle. This is determined by the variation along the upper branch of the hysteresis loop. As the a-c voltage rises in the first half cycle it now takes longer to reach saturation because of the greater overall change in flux. The high unsaturated impedance up to this time cuts off the load current. Its rise at saturation is shown at i_2 and is lower than i_1 because it starts to flow later in the cycle, after the voltage has begun to decrease.

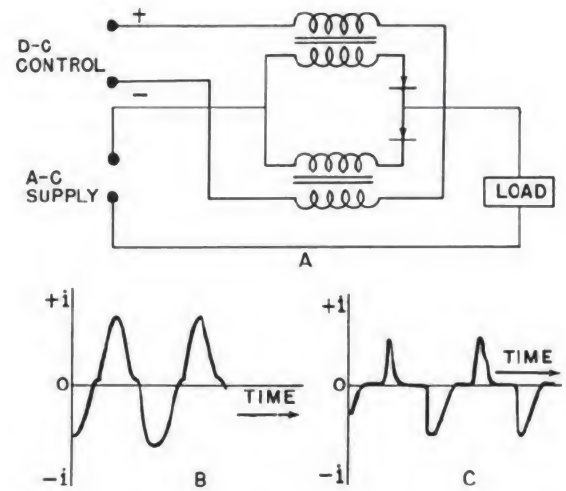
Thus by varying the d-c control current from a small negative to a small positive value the load current is increased from zero to maximum as core saturation occurs late or early in the conducting portion of each load cycle. As long as the inductor is not saturated, only a small current flows in the load because of the high reactance of the coil; when the inductor is saturated by the small d-c control signal, a large current flows unimpeded through the load. This is the basic principle of operation of saturable reactors in magnetic amplifiers.

ANALOGY TO THYRATRONS

Magnetic amplifiers and thyratrons are similar in function. Both prevent the flow of current through a load until a control signal is applied. After the control signal has been applied both are effectively reduced to a low impedance that permits load current to flow. The thyratron loses control when ionization occurs and is cut off by reducing plate voltage. The saturable reactor is cut off (high impedance established) when the load current falls below the value corresponding to core flux saturation and the unsaturated condition in the core is reestablished. The losses in the magnetic amplifier are less than those in the thyratron and the efficiency of the magnetic amplifier is higher than that of the thyratron.

OUTPUT WAVEFORMS

The output waveform is similar to that of a grid-controlled rectifier such as the thyratron. Although the preceding analysis has been made for a simple half-wave rectifier under ideal conditions, the operation and waveforms obtained with practical circuits are very similar. In the circuit of figure 19-3A, the magnetic amplifier produces an a-c output and might be used to control an a-c relay. The waveform resulting with zero control current is shown in figure 19-3B, and is seen to approximate a sine curve of load current. When a small negative control current is applied, the waveform is reduced in amplitude as shown in figure 19-3C. Thus the output voltage appearing across the load can be varied from zero to full value by introducing a small d-c control current that is varied between narrow limits.



1.293
Figure 19-3.—Magnetic amplifier. (A) Circuit; (B) Load current waveform with zero control current; (C) Load current waveform with a small negative signal.

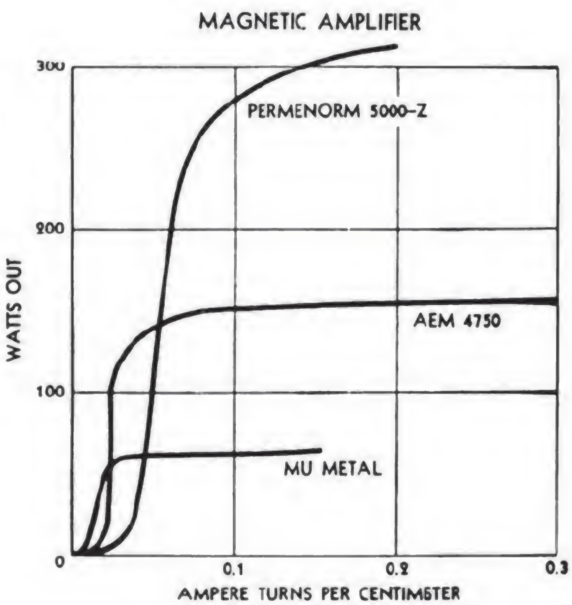
CORE FACTORS

A good core material has high permeability (μ). Permeability is a measure of the ability of a material to develop magnetic flux compared to that of air when both are under the influence of the same magnetizing force. It is expressed by the equation

$$\mu = \frac{B}{H}$$

where B is the flux density produced in a core placed in a magnetizing field H. Thus, a core with high permeability can produce a high flux density with a relatively low magnetizing force.

Another requirement of a suitable core material is that it have a low coercive force. Coercive force is the magnetizing force required to reduce the residual flux to zero. In the rectangular hysteresis loops of figure 19-1A and B, the coercive force and the magnetizing force required to saturate the cores are nearly equal. Thus, in general, a core with a low coercive



1.294

Figure 19-4.—Relation between magnetizing force and controlled power output for three core materials of 60 grams each.

force requires only a small magnetizing force to saturate it. This means that only a small change in d-c control current is needed to vary the load current from zero to full value. In some applications where only a small control current is available it is essential that a core with low coercive force be used.

Figure 19-4 shows the relation between the magnetizing force in ampere turns per centimeter and the power in watts controlled by the reactor for three core materials of equal size. The watts output controlled by the reactor for the same control current are highest for Permenorm, less for AEM-4750 and least for Mu Metal. If the available control signal is only large enough to produce a magnetizing force of 0.02 ampere turns per centimeter, Mu Metal is the only one of the three cores that can be used to control power output because the other two will not saturate with the maximum control current.

TIME DELAY

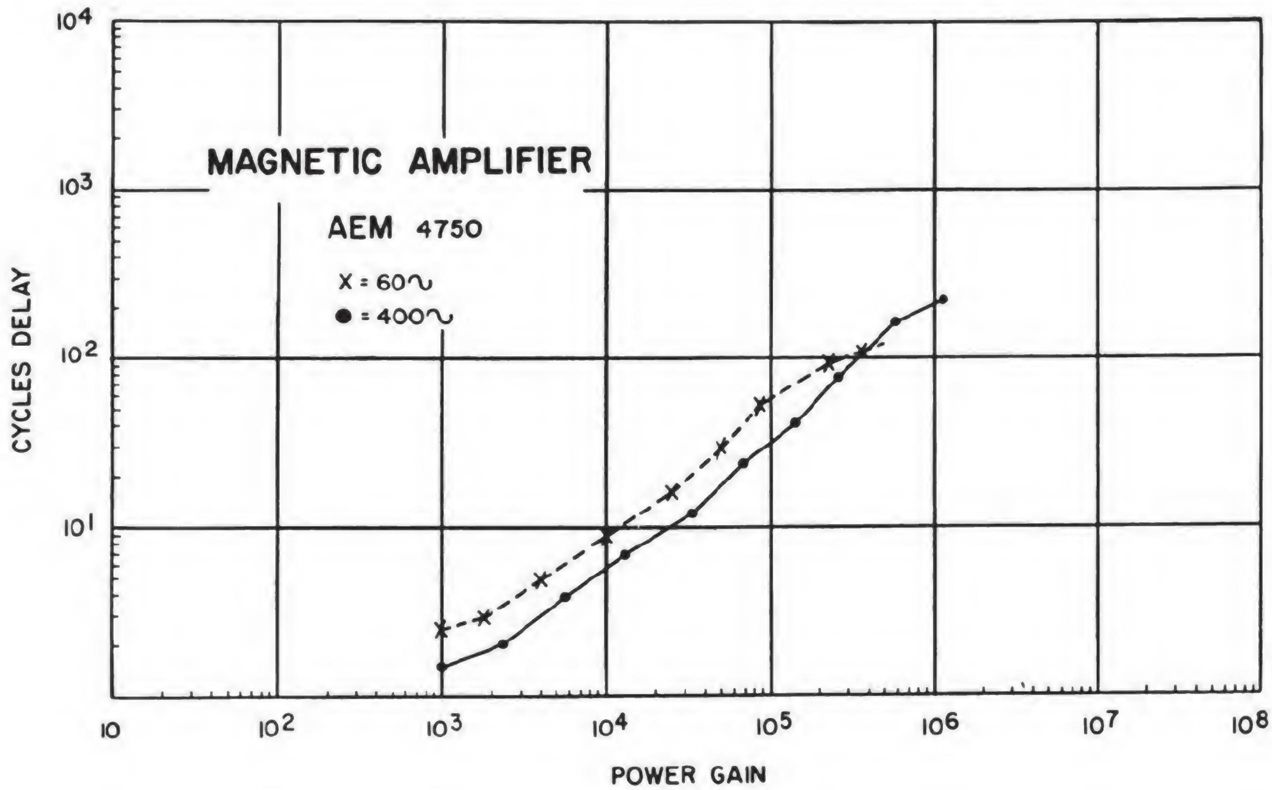
If a d-c voltage of constant amplitude is applied to the control winding of a saturable reactor, the load current will not rise instantly because of the inductance of the windings. The time delay between a change of input control current and the corresponding change in load current depends on (1) the amount of feedback—that is, feeding back part of the output through auxiliary windings or by self-saturation, (2) the inductance and resistance in the control winding circuit, and (3) the frequency of the load circuit. Time delay increases with amplification and in high gain magnetic amplifiers becomes a limiting factor in their practical application. Small units are available with time delay of only a few cycles and amplifications of 1,000 to 10,000 per stage. Where longer time delays do not prevent successful operation, as in the case of lighting controls, larger reactors are built. Some are in service with ratings of several hundred kva and time delays of several seconds. Time delay is reduced in various ways: (1) by adding resistance in the control circuit, (2) by changing the length of the effective air gap, in the magnetic circuit or (3) by using a 400-cycle a-c source instead of a 60-cycle source in the load circuit. The relation between cycles delay and power gain is shown in figure 19-5 for a 60-cycle a-c source and a 400-cycle a-c source. At a power gain of 10^4, there is a delay of seven cycles of the 400-cps signal (0.018 second) and 9 cycles of the 60-cps signal (0.15 second). The time delay at any frequency can be reduced by reducing the gain of the amplifier.

One result of the time delay is that the frequency of the control signal must be lower than that of the a-c source. This is a severe limitation as compared with vacuum-tube amplifiers, in which the maximum frequency is limited only by interelectrode capacities and transit time.

As has been mentioned, the delay in the magnetic amplifier depends in part on the gain. At fairly high gains the signal frequency is limited to about 10 percent of the a-c source frequency. At very low gains the signal frequency can be more than 50 percent of the a-c source frequency. The source frequency can be as high as can be obtained with suitable choice of available core materials. Frequencies in megacycles have been used to energize magnetic amplifiers.

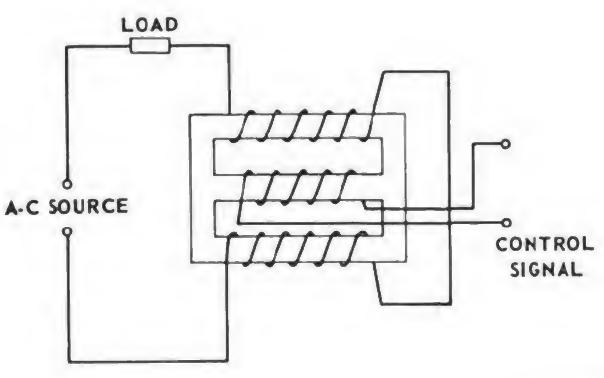
A-C OUTPUT, D-C OUTPUT, AND FEEDBACK

A "three-legged" saturable reactor is shown in figure 19-6. The lines of flux produced in the



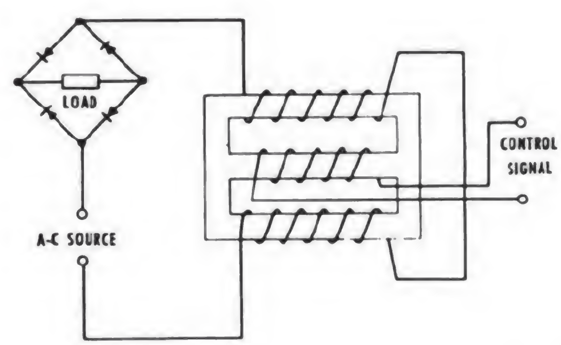
1.295

Figure 19-5.—Curves of cycles delay vs. power gain with 60- abd 400-cps sources.



1.296X

Figure 19-6.—"Three-legged" saturable reactor.

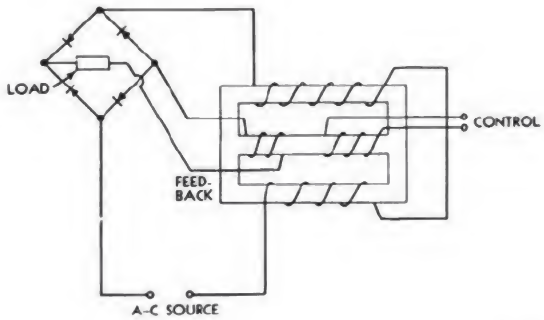


1.297X

Figure 19-7.—Magnetic amplifier circuit with d-c output to the load.

core by the a-c load current flow around the outer two legs and no a-c signal is induced in the control winding on the center leg. When the control signal is applied, the core saturates and large a-c currents flow to the load.

The a-c current to the load can be rectified as in figure 19-7, which shows a full-wave bridge



1.298X
Figure 19-8.—Simple magnetic amplifier with d-c output and series feedback.

rectifier connected across the load. The bridge rectifies the a-c output so that the load current follows the control-signal variations within the frequency limitations of the magnetic amplifier. Dry-disk rectifiers are usually employed for this purpose.

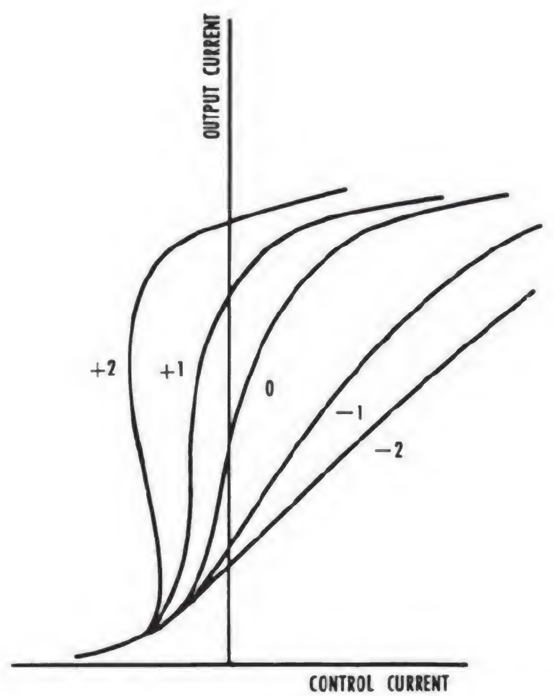
An additional winding on the control leg of the saturable reactor can be connected with the d-c output of the amplifier, as shown in figure 19-8. The feedback can be positive or negative. Positive feedback makes the reactor more sensitive to changes in control current; negative feedback produces less sensitivity but increases the linearity of the transfer curve (figure 19-9). Figure 19-9 shows the transfer curves for two positive and two negative feedback ratios and for zero feedback. The curves are numbered arbitrarily + 1, + 2, - 1, and - 2. Note that in the curve marked + 2, there is sufficient positive feedback to make the amplifier unstable. For maximum sensitivity, positive feedback is added until the transfer curve is very steep and without negative slope. This is a critical adjustment. For example, 4,002 turns on the feedback winding may be the point of optimum sensitivity. Increasing the number of turns to 4,004 can cause instability. Reducing the number of turns to 4,000 can cause significant loss in sensitivity. For maximum gain, the turns in the feedback winding are greater by a small percentage than those in the power winding. As the feedback depends on rectified load current, a fixed d-c bias is required to minimize the load current under no-signal conditions.

CIRCUITS

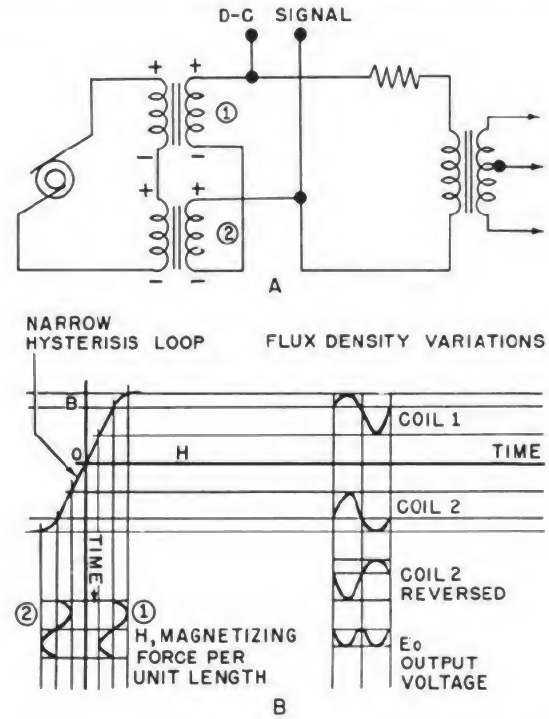
VOLTAGE AMPLIFIERS

Figure 19-10 shows a typical magnetic voltage amplifier. The a-c source energizes two toroidal cores, the primaries of which are connected in series-aiding and the secondaries of which are connected in series-opposing.

The two secondary coils are balanced so that when the d-c (control) signal is zero, the net voltage across the output terminals is zero. However, if a d-c or a slowly varying control signal is applied across the secondary, it produces a magnetic bias in opposite directions in the two secondaries, as indicated in figure 19-10B. The hysteresis loop is narrowed to the width of a line to simplify the projection of the primary exciting current for the coils into corresponding flux variations. The exciting curves are plotted in phase with each other and represent a single value of H, the intensity of magnetizing force per unit of coil length, because the two primaries are connected in series.



1.299X
Figure 19-9.—Transfer curves showing the effect of both positive and negative series feedback.



1.300
Figure 19-10.—Magnetic voltage amplifier. (A) Circuit; (B) Voltage and flux analysis.

The resulting flux density variation in coil 1 is projected to the upper right of the hysteresis loop and the flux density variation in coil 2 is projected directly under it to the lower right of the hysteresis loop. These flux density variations appear at opposite ends of the hysteresis loop in order to establish the sense of magnetic bias in opposite directions because the d-c signal current flows in opposite directions in the two secondaries.

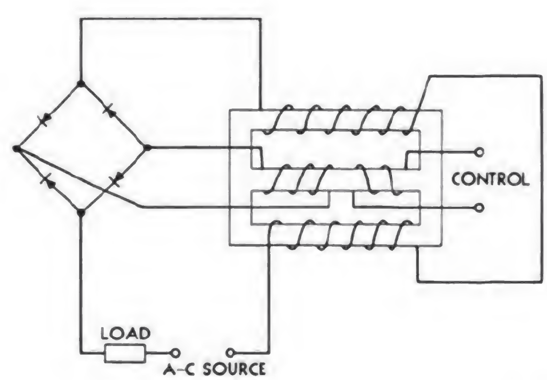
The secondaries are connected in series opposition, hence the flux density curve of coil 2 is reversed in order to combine it properly with the flux density curve of coil 1 to obtain the output curve. It is assumed that the flux density curves for coils 1 and 2 are a measure of their secondary voltages. The output curve is found by combining the flux density curve for coil 1 and the flux density curve reversed for coil 2. The output curve is plotted to a different scale to emphasize the fact that it is a curve of voltage. It appears directly below the flux density curves for coils 1 and 2 (reversed) as a point by point summation of them. If the a-c voltages induced in the two secondaries were equal as with zero control signal the output would be zero as previously mentioned. With the d-c signal the a-c voltages are no longer equal, and the resultant a-c voltage appears across the output.

Because of the phase-reversal connection of the secondary coils (the secondaries are connected in series-opposing), a pulse of voltage is developed across the load for each half cycle of a-c source current. Therefore, the output is an alternating current of twice the frequency of the a-c source, as in a full-wave rectifier. If direct current is desired in the load, the output signal can be rectified as shown in figure 19-8.

Voltage gains on the order of 10^6 have been obtained with Permalloy cores. Use of Supermalloy has yielded gains of 10^7.

POWER AMPLIFIERS

Figure 19-11 is the circuit diagram of a power amplifier with feedback. Note that the current to the load is not rectified—hence the load receives a-c power only. This is the only difference between the circuit of figure 19-11 and that of figure 19-8. The power windings are in series-aiding and in series with the load. The a-c lines of flux do not cut the feedback and signal windings, on the center leg of the core, so that no a-c signal is induced in the feedback and signal windings. The bridge



1.301X
Figure 19-11.—Magnetic power amplifier with series feedback.

circuit rectifies only the current to the feedback windings. The feedback can be positive or negative, depending on the connection of the windings. Positive feedback results in greater power gain, negative feedback in greater linearity.

For a zero signal the power windings are adjusted so that the maximum flux is just below saturation. When a d-c signal is applied, the flux in one coil is above the knee of the curve for most of one-half cycle, and the reactance of the coil is removed. If the d-c signal is increased until an entire half cycle is above saturation, then a further increase in signal results in no increase in load current. Power gains up to 10^8 are possible with a circuit like the one shown in figure 19-11.

OTHER APPLICATIONS

In applications where frequency response is not important, the sturdiness and simplicity of magnetic amplifiers have led to its use in hundreds of applications. It is used in servomechanism controls, voltage regulators, automatic battery chargers, d-c and audio amplifiers magnetic mines, theater-lamp and furnace controls, hydraulic transmission controls, and many other applications. An important and a desirable feature of the magnetic amplifier is the electrical isolation between the input (control) and output (load) circuits. This, of course, is true of most transformer applications. Some typical applications in the navy are gun director control and antenna position control.

APPENDIX I

GREEK ALPHABET

Name	Capital	Lower case	Designates
Alpha	A	α	Angles.
Beta.	B	β	Angles, flux density.
Gamma.	Γ	γ	Conductivity.
Delta	Δ	δ	Variation of a quantity, increment.
Epsilon.	E	ϵ	Base of natural logarithms (2.71828).
Zeta.	Z	ζ	Impedance, coefficients, coordinates.
Eta	H	η	Hysteresis coefficient, efficiency.
Theta	Θ	θ	Phase angle.
Iota	I	ι	
Kappa.	K	κ	Dielectric constant, coupling coefficient, susceptibility.
Lambda	Λ	λ	Wavelength.
Mu.	M	μ	Permeability, micro, amplification factor.
Nu	N	ν	Reluctivity.
Xi	Ξ	ξ	
Omicon.	O	o	
Pi	Π	π	3.1416
Rho	P	ρ	Resistivity.
Sigma.	Σ	σ	Summation, standard deviation.
Tau	T	τ	Time constant, time-phase displacement.
Upsilon.	Υ	υ	
Phi	Φ	ϕ	Angles, magnetic flux.
Chi	X	χ	
Psi	Ψ	ψ	Dielectric flux, phase difference.
Omega	Ω	ω	Ohms (capital), angular velocity ($2\pi f$).

APPENDIX II
FORMULAS

Ohm's Law for D-C circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

Resistors in Series

$$R_T = R_1 + R_2 \ldots$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots$$

Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force	Volt, E, or emf	Gilberts, F, or mmf.
Flow	Ampere, I	Flux, Φ, in maxwells.
Opposition	Ohms, R.	Reluctance, $\Re$.
Law	Ohms law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\Re}$.
Intensity of force	Volts per cm of length.	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length.
Density	Current density—for example, amperes per cm^2.	Flux density—for example, lines per cm^2, or gausses.

R-L Circuit Time Constant equals

$$\frac{L \text{ (in henrys)}}{R \text{ (in ohms)}} = t \text{ (in seconds), or}$$

$$\frac{L \text{ (in microhenrys)}}{R \text{ (in ohms)}} = t \text{ (in microseconds)}$$

R-C Circuit Time Constants equals

R (ohms) $\times$ C (farads) = t (seconds)

R (megohms) $\times$ C (microfarads) = t (seconds)

R (ohms) $\times$ C (microfarads) = t (microseconds)

R (megohms) $\times$ C (micromicrofarads) = t (microseconds)

Capacitors in Series

Two capacitors

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \ldots$$

Capacitors in Parallel $C_T = C_1 + C_2 \ldots$

Capacitive Reactance ($X_C = \frac{1}{2\pi fC}$)

Impedance in an R-C Circuit (Series)

$$Z = \sqrt{R^2 + X_C^2}$$

Inductors in Series

$$L_T = L_1 + L_2 \ldots$$

(No coupling between coils)

Inductors in Parallel

Two inductors

$$L_T = \frac{L_1 L_2}{L_1 + L_2}$$

(No coupling between coils)

More than two

$$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \ldots$$

(No coupling between coils)

Inductive Reactance

$$X_L = 2\pi fL$$

Q of a Coil

$$Q = \frac{X_L}{R}$$

Impedance of an R-L Circuit (Series)

$$Z = \sqrt{R^2 + X_L^2}$$

Impedance with R, C, and L in Series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Parallel Circuit Impedance

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Sine-Wave Voltage Relationships

Average value

$$E_{ave} = \frac{2}{\pi} \times E_{max} = 0.637E_{max}$$

Effective or r.m.s. value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707E_{max} = 1.11E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2}\ E_{eff} = 1.414E_{eff} = 1.57E_{ave}$$

Voltage in an a-c circuit

$$E = IZ = \frac{P}{I \times P.F.}$$

Current in an a-c circuit

$$I = \frac{E}{Z} = \frac{P}{E \times P.F.}$$

Power in A-C Circuit

Apparent power = EI

True power (P = EI cos θ = EI $\times$ P.F.

Power Factor

$$P.F. = \frac{P}{EI} = \cos\theta$$

$$\cos\theta = \frac{\text{true power}}{\text{apparent power}}$$

Transformers

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44\ BAfN10^{-8}$$

Turns ratio equals

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Secondary current

$$I_s = I_p \cdot \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \frac{N_s}{N_p}$$

Three-Phase Voltage and Current Relationships

With Wye connected windings

$$E_{line} = 1.732E_{coil} = \sqrt{3}\ E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732I_{coil}$$

With wye or delta connected winding

$$P_{coil} = E_{coil}\ I_{coil}$$

$$P_t = 3P_{coil}$$

$$P_t = 1.732E_{line}\ I_{line}$$

(To convert to true power multiply by $\cos\theta$)

Resonance

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonance

$$Z \text{ (at any frequency)} = R + j(X_L - X_C)$$

$$Z \text{ (at resonance)} = R$$

Parallel resonance

$$A \text{ (at any frequency)} = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{{X_L}^2}{R} = QX_L = \frac{L}{CR}$$

Band width

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

Tube characteristics

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} \text{ } (i_p \text{ constant})$$

$$\mu = g_m r_p$$

A-c plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} \text{ } (e_g \text{ constant})$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} \text{ } (e_p \text{ constant})$$

Decibels

Power ratio

$$db = 10 \log_{10} \frac{P_2}{P_1}$$

Current and voltage ratio

$$db = 20 \log_{10} \frac{I_2\sqrt{R_2}}{I_1\sqrt{R_1}}$$

$$db = 20 \log_{10} \frac{E_2\sqrt{R_1}}{E_1\sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula.

When reference level is one milliwatt

$$dbm = 10 \log_{10} \frac{P}{0.001} \text{ (when P is in watts)}$$

Synchronous Speed of Motor

$$\text{r.p.m.} = \frac{120 \times \text{frequency}}{\text{number of poles}}$$

Radar Power Relationships

$$\text{Duty cycle} = \frac{\text{average power}}{\text{peak power}} = \frac{\text{pulse width}}{\text{pulse repetition time}}$$

Average power = peak power × duty cycle

$$\text{Peak power} = \frac{\text{average power} \times 10^6}{\text{pulse width in } \mu\text{sec.} \times \text{PRF}}$$

APPENDIX III

LAWS OF EXPONENTS

The following table shows some multiples of 10, their equivalent powers of ten, their prefixes, and their symbols which are used to write a number in scientific form.

Number		Powers of Ten	Prefix	Symbol
1,000,000,000,000	=	10^{12}	Tera	T
1,000,000,000	=	10^{9}	Giga	G
1,000,000	=	10^{6}	Mega	M
100,000	=	10^{5}		
10,000	=	10^{4}		
1,000	=	10^{3}	Kilo	k
100	=	10^{2}	Hecto	h
10	=	10^{1}	Deka	dk
1	=	10^{0}		
0.1	=	10^{-1}	Deci	d
0.01	=	10^{-2}	Centi	c
0.001	=	10^{-3}	Milli	m
0.0001	=	10^{-4}		
0.00001	=	10^{-5}		
0.000001	=	10^{-6}	Micro	μ
0.000000001	=	10^{-9}	Nano	n
0.000000000001	=	10	Pico	p

To multiply like (with same base) exponential quantities, add the exponents. In the language of algebra the rule is $a^m \times a^n = a^{m+n}$.

$$10^4 + 10^2 = 10^{4+2} = 10^6$$

$$0.003 \times 825.2 = 3 \times 10^{-3} \times 8.252 \times 10^2 =$$

$$24.756 \times 10^{-1} = 2.4756$$

To divide like exponential quantities, subtract the exponents. In the language of algebra the rule is

$$\frac{a^m}{a^n} = a^{m-n} \text{ or } 10^8 + 10^2 = 10^6$$

$$3,000 + 0.015 = (3 \times 10^3) + (1.5 \times 10^{-2}) =$$

$$2 \times 10^5 = 200,000$$

To raise an exponential quantity to a power, multiply the exponents. In the language of algebra $(x^m)^n = x^{m\,n}$.

$$(10^3)^4 = 10^{3 \times 4} = 10^{12}$$

$$2,500^2 = (2.5 \times 10^3) = 6.25 \times 10^6 =$$
$$6,250,000$$

Any number (except zero) raised to the zero power is one. In the language of algebra $x^0 = 1$

$$x^3 \div x^3 = 1$$

$$10^4 \div 10^4 = 1$$

Any base with a negative exponent is equal to 1 divided by the base with an equal positive exponent. In the language of algebra

$$x^{-a} = \frac{1}{x^a}$$

$$10^{-2} = \frac{1}{10^2} = \frac{1}{100}$$

$$5a^{-3} = \frac{5}{a^3}$$

$$(6a)^{-1} = \frac{1}{6a}$$

To raise a product to a power, raise each factor of the product to that power.

$$(2 \times 10)^2 = 2^2 \times 10^2$$

$$3,000^3 = (3 \times 10^3)^3 = 27 \times 10^9$$

To find the nth root of an exponential quantity, divide the exponent by the index of the root. Thus, with nth root of $a^m = a^{m/n}$.

$$\sqrt{x^6} = x^{6/2} = x$$

$$\sqrt[3]{64 \times 10^3} = 4 \times 10 = 40$$

APPENDIX IV

AN. RADIO-FREQUENCY CABLES

AN. TYPE NUMBER	INNER CONDUCTOR	DIELECTRIC MATERIAL	SHIELDING BRAID	PROTECTIVE COVERING	NOMINAL OVER-ALL DIA (in.)	NOMINAL IMPEDANCE (ohms)	NOMINAL CAP. ($\mu\mu f$/ft)	R-M-S MAX OPERATING VOLTAGE (volts)	ATTENUATION IN DECIBELS (APPROX) PER 100 FT				
									50 MC	100 MC	200 MC	500 MC	1000 MC
RG-5/U	16 AWG copper	A	Copper	Vinyl	0.332	52.5	28.5	3000		2.80	4.00	6.00	10.00
RG-6/U	21 AWG copperweld	A	Inner: silver-coated copper. Outer: copper.	Vinyl (noncon-taminating)	0.332	76.0	20.0	2700		2.50	4.00	7.00	10.50
RG-7/U	19 AWG copper	A or B	Copper	Vinyl	0.370	90–105	12.5 14.0 (max)	1000	1.50	1.90	3.20	5.00	7.50
RG-8/U	7/21 AWG copper	A	Copper	Vinyl	0.405	52.0	29.5	4000	1.37	2.10	3.15	5.50	8.50
RG-9/U	7/21 AWG silvered copper	A	Inner: silver-coated copper. Outer: copper.	Vinyl (noncon-taminating)	0.420	51.0	30.0	4000	1.37	2.10	3.15	5.50	8.50
RG-9A/U	7/21 AWG silvered copper	A	Silvered copper	Vinyl (noncon-taminating)	0.420	51.0	30.0	4000	1.37	2.10	3.15	5.50	8.50
RG-10/U	7/21 AWG copper	A	Copper	Vinyl (noncon-taminating) armor	0.475 (max)	52.0	29.5	4000	1.37	2.10	3.15	5.50	8.50
RG-11/U	7/26 AWG tinned copper	A	Copper	Vinyl	0.405	75.0	20.5	4000	1.27	1.90	2.85	5.00	7.70
RG-12/U	7/26 AWG tinned copper	A	Copper	Vinyl (noncon-taminating) armor	0.475	75.0	20.5	4000	1.27	1.90	2.85	5.00	7.70
RG-13/U	7/26 AWG tinned copper	A	Copper	Vinyl	0.420	74.0	20.5	4000	1.27	1.90	2.85	5.00	7.70
RG-14/U	10 AWG copper	A	Copper	Vinyl (noncon-taminating)	0.545	52.0	29.5	5500		1.40	2.00	3.20	5.00
RG-15/U	15 AWG copperweld	A	Copper	Vinyl	0.545	76.0	20.0	5000		1.50	2.10	4.00	6.00
RG-16/U	Copper tube; nom dia, 0.125 in.	A	Copper	Vinyl	0.630	52.0	29.5	6000		1.25	1.90	3.20	5.20
RG-17/U	0.188 copper	A	Copper	Vinyl (noncon-taminating)	0.870	52.0	29.5	11,000	0.550	0.850	1.30	2.45	4.00

AN. RADIO-FREQUENCY CABLES (Cont)

AN. TYPE NUMBER	INNER CONDUCTOR	DIELECTRIC MATERIAL	SHIELDING BRAID	PROTECTIVE COVERING	NOMINAL OVER-ALL DIA (in.)	NOMINAL IMPEDANCE (ohms)	NOMINAL CAP. (μμf/ft)	R-M-S MAX OPERATING VOLTAGE (volts)	ATTENUATION IN DECIBELS (APPROX) PER 100 FT				
									50 MC	100 MC	200 MC	500 MC	1000 MC
RG-18/U	0.188 copper	A	Copper	Vinyl (noncon-taminating) armor	0.945 (max)	52.0	29.5	11,000	0.550	0.850	1.30	2.45	4.00
RG-19/U	0.250 copper	A	Copper	Vinyl (noncon-taminating)	1.120	52.0	29.5	14,000		0.650	1.15	2.10	3.40
RG-20/U	0.250 copper	A	Copper	Vinyl (noncon-taminating) armor	1.195 (max)	52.0	29.5	14,000		0.650	1.15	2.10	3.40
RG-21/U	16 AWG resistance wire	A	Inner: silver-coated copper. Outer: copper.	Vinyl (noncon-taminating)	0.332	53.0	29.0	2700		14.00	19.00	30.00	42.00
RG-22/U	2-conductor 7/0.0152 copper	A	Tinned copper (single)	Vinyl	0.405	95.0	16.0	1000	2.50	3.30	4.30		
RG-23/U	2-conductor 7/21 AWG copper	A	Copper (individual inner; common outer)	Vinyl	0.650 x 0.945	125.0	12.0	3000	1.10	1.80	2.60		
RG-25A/U	19/0.0117 tinned copper	E	Tinned copper	Synthetic rubber	0.505	48.0	50.0	8000 (peak)					
RG-26A/U	19/0.0117 tinned copper	E	Tinned copper	Synthetic rubber armor	0.505	48.0	50.0	8000 (peak)					
RG-27/U	19/0.0185 tinned copper	D	Tinned copper	Vinyl armor	0.675 (max)	48.0	50.0	15,000 (peak)					
RG-28/U	19/0.0185 tinned copper	D	Inner: tinned copper. Outer: galvanized steel.	Synthetic rubber	0.805	48.0	50.0	15,000 (peak)					
RG-29/U	20 AWG copper	A	Tinned copper	Polyethylene	0.184	53.5	28.5	1900	2.90	4.00	5.90	10.00	17.00
RG-34/U	7/21 AWG copper	A	Copper	Vinyl	0.625	71.0	21.5	5200	1.20	1.80	2.80		

AN. RADIO-FREQUENCY CABLES (Cont)

AN. TYPE NUMBER	INNER CONDUCTOR	DIELECTRIC MATERIAL	SHIELDING BRAID	PROTECTIVE COVERING	NOMINAL OVER-ALL DIA (in.)	NOMINAL IMPEDANCE (ohms)	NOMINAL CAP. ($\mu\mu f/ft$)	R-M-S MAX OPERATING VOLTAGE (volts)	ATTENUATION IN DECIBELS (APPROX) PER 100 FT				
									50 MC	100 MC	200 MC	500 MC	1000 MC
RG-35/U	9 AWG copper	A	Copper	Vinyl (noncontaminating) armor	0.945	71.0	21.5	10,000		0.70	1.20	2.50	4.00
RG-38/U	17 AWG tinned copper	C	Tinned copper	Polyethylene	0.312	52.5	38.0	1000	6.00	9.80	14.00	26.00	44.00
RG-39/U	22 AWG tinned copperweld	C	Tinned copper	Polyethylene	0.312	72.5	28.0	1000	6.00	9.80	14.00	26.00	44.00
RG-40/U	22 AWG tinned copperweld	C	Tinned copper	Synthetic rubber	0.420	72.5	28.0	1000	6.00	9.80	14.00	26.00	44.00
RG-41/U	16/30 AWG tinned copper	C	Tinned copper	Neoprene	0.425	67.5	27.0	3000					
RG-42/U	21 AWG high-resistance wire	A	Silvered copper (2 braids)	Vinyl (noncontaminating)	0.342	78.0	20.0	2700		15.00	22.00	33.00	50.00
RG-54A/U	7/0.0152 copper	A	Tinned copper	Polyethylene	0.250	58.0	26.5	3000		3.00	4.40		
RG-55/U	20 AWG copper	A	Tinned copper	Polyethylene	0.206 (max)	53.5	28.5	1900	2.90	4.00	5.90	10.00	17.00
RG-57/U	2-conductor 7/21 AWG copper	A	Tinned copper (single)	Vinyl	0.625	95.0	17.0	3000	1.80	2.90	4.60		
RG-58/U	20 AWG copper	A	Tinned copper	Vinyl	0.195	53.5	28.5	1900	2.90	4.00	5.90	10.00	17.00
RG-58A/U	20 AWG Class C stranded tinned copper	A	Tinned copper	Vinyl	0.195	52.0	28.5	1900	3.10	5.00	8.00	13.00	21.00
RG-59/U	22AWG copperweld	A	Copper	Vinyl	0.242	73.0	21.0	2300	2.30	4.00	5.50	10.00	14.00
RG-62/U	22 AWG copperweld	A or B	Copper	Vinyl	0.242	93.0	13.5 14.5 (max)	750	2.10	3.10	4.30	7.00	10.00

AN. RADIO-FREQUENCY CABLES (Cont)

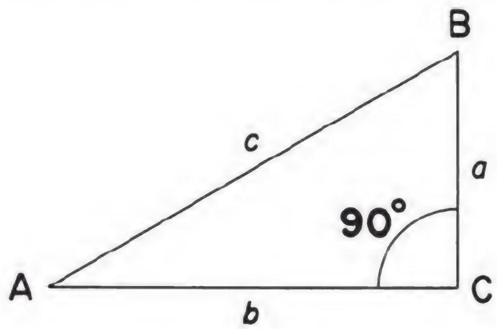
AN. TYPE NUMBER	INNER CONDUCTOR	DIELECTRIC MATERIAL	SHIELDING BRAID	PROTECTIVE COVERING	NOMINAL OVER-ALL DIA (in.)	NOMINAL IMPEDANCE (ohms)	NOMINAL CAP. ($\mu\mu f/ft$)	R-M-S MAX OPERATING VOLTAGE (volts)	ATTENUATION IN DECIBELS (APPROX) PER 100 FT				
									50 MC	100 MC	200 MC	500 MC	1000 MC
RG-63/U	22 AWG copperweld	A or B	Copper	Vinyl	0.405	125.0	10.0 11.0 (max)	1000	1.30	2.00	2.80	4.40	6.40
RG-64A/U	19/0.0117 tinned copper	E	Tinned copper	Synthetic rubber	0.475	48.0	50.0	8000 (peak)					
RG-65/U	No. 32 Formex F; helix dia, 0.128 in.	A	Copper (single)	Vinyl	0.405	950.0	44.0	1000					
RG-71/U	22 AWG copperweld	A	Inner: plain copper. Outer: tinned copper.	Polyethylene	0.250	93.0	13.5 14.5 (max)	750	2.10	3.10	4.30	7.00	10.00
RG-74/U	10 AWG copper	A	Copper	Vinyl (noncontaminating) armor	0.615	52.0	29.5	5500		1.40	2.00	3.20	5.00

A–Stabilized polyethylene. B–Polymeric resin mixture. C–Synthetic rubber compound.
D–Layer of synthetic rubber dielectric between thin layers of conducting rubber.
E–Inner layer of conducting rubber; center layer of synthetic rubber; outer layer of red insulating synthetic rubber.

APPENDIX V

TRIGONOMETRY AND THE SLIDE RULE

The following plane trigonometric formulas will be employed in the slide rule solutions of problems considered in this appendix. Referring to figure V-1, the following definitions and relationships for the right triangle are given.



1.376

Figure V-1.—Right triangle.

$$\text{Sine A} = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{a}{c},$$

$$\text{Cosine A} = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{b}{c},$$

$$\text{Tangent A} = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{a}{b},$$

THE S (SINE) AND SRT (SINE, RADIAN, TANGENT) SCALES

The graduations on the sine scales S and SRT (sometimes labeled the ST Scale) represent angles. We shall speak of setting the slide rule hairline to an angle or drawing an angle under the hairline.

There are two S scales, one called the S or sine scale specified by the black numbers on S; the other S red or the cosine scale specified by the red numbers. The sine scale is the predominant scale. In the paragraphs that follow, any reference to an angle on a trigonometric scale will be to the angle in black unless otherwise indicated.

The scale designated SRT is, as its name indicates, used to find sines, radian equivalents, and tangents of angles, ranging from 0.573 degrees to 5.73 degrees approximately. In this appendix our interest is mainly in sines.

Each small inscription at the right of a scale is called the legend of the scale. A legend of a scale specifies a range of values associated with the function represented by the scale. Thus the legend 0.1 to 1.0 of scale S specifies that the sines of the angles on S and the cosines of angles on S red range from 0.1 to 1, and the legend 0.01 to 0.1 of the SRT scale indicates that sines (or radian equivalents and tangents) of angles on SRT range from 0.01 to 0.1.

Example. Evaluate (a) sin 30°.
(b) sin 2.86°.

Solution. (a) Opposite 30° on S, read on C scale (or D scale when rule is closed) 0.50. The result 0.50 lies between 0.1 and 1.0, that is, within the range specified by the legend 0.1 to 1.0 of S.

Solution. (b) Opposite 2.86° on SRT, read on C scale 0.05. The result 0.05 lies between 0.01 and 0.1, that is, within the range specified by the legend of 0.01 to 0.1 of SRT.

EXERCISES

Find the sine of each of the following angles.

(1) 32°	(4) 2.61°	(7) 3.34°	(10) 90°
(2) 64°	(5) 48.2°	(8) 56.3°	(11) 86.3°
(3) 1.86°	(6) 72°	(9) 4.81°	(12) 45°

Find the cosine of each of the angles in the above exercise. Use the red numbers on the S scale.

For angles greater than 84.26°, use cos A = sin (90° - A) on scale C. For example, set the hairline to 20° on S, at the hairline on C read

0.342 = sin 20° = cos 70°. Thus to find cosine 87.2°, write cosing 87.2° = sin 2.8° and set the hairline to 2.8° on SRT, at the hairline on C read 0.0488 = sin 2.8° = cos 87.2°.

Find x in each of the following equations:

(13) sin x = 0.5.	(16) sin x = 0.1.
(14) sin x = 0.68.	(17) sin x = 0.16.
(15) sin x = 0.485.	(18) sin x = 0.0366.

Find cos x in each of the above equations.

LAW OF SINES

In any triangle such as ABC of figure V-1, A, B, and C represent the angles and a, b, and c, represent, respectively, the lengths of the sides opposite these angles. Thus, the following relations hold true.

Law of sines: $\dfrac{\sin A}{a} = \dfrac{\sin B}{b} = \dfrac{\sin C}{c}$

Law of cosines: $A^2 = b^2 + c^2 - 2bc \cos A.$

$A + B + C = 180°$

OPERATIONS INVOLVING THE S AND SRT SCALES

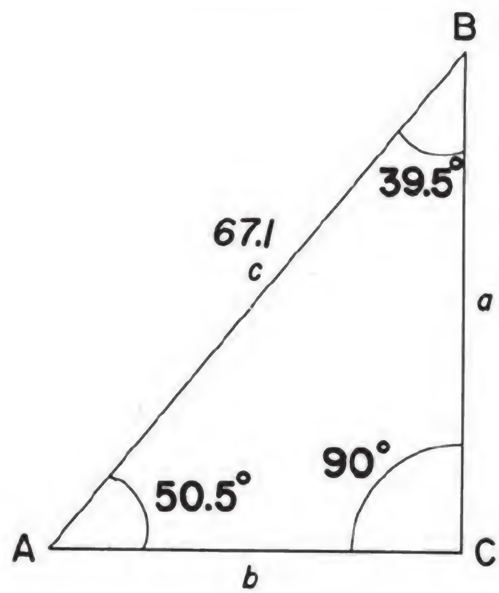
Combined operations and proportions by means of the S and SRT scales are accomplished similarly to square roots and reciprocals by means of the B scale and the CI scale. See Mathematics, Vol. I, NavPers 10069-B. Thus to find 6 sin 30°, opposite 6 on D set index of C, opposite 30° on S read on D, 3.0 = 6 sin 30°. The decimal point is placed after observing on the slide rule that sin 30° is 0.5 and therefore that 6 sin 30° is 6 X 0.5 = 3.0. The legend of the S scale indicates the value of sin 30° is a value between 0.1 and 1.0.

To find 6/ cos 30°, opposite 6 on D scale set 30° of S red, opposite index of C read on D, 6.928 = 6/ cos 30°. The decimal point is placed after observing on the slide rule that the cosine of 30° is approximately 0.86 and therefore 6/ cos 30° is nearly equal to 6/0.86 = 7. Here again the legend 0.1 to 1.0 is S indicates the value of the cosine 30°.

SOLVING THE RIGHT TRIANGLE

To solve the right triangle illustrated in figure V-2 (note that 90° and 67.1 are opposite),

opposite 671 on D set 90° of S,
opposite 50.5° on S read a = 51.75 on D,
opposite 39.5° on S read b = 42.7 on D.



1.377

Figure V-2. —Right triangle.

To solve the right triangle illustrated in figure V-3,

opposite 625 on D set 90° of S,
opposite 524 on D read B = 57° on S,
compute A = 90° - B = 33°,
opposite 33° on S read a = 3.4 on D.

To solve any triangle for which a side and the angle opposite are known,

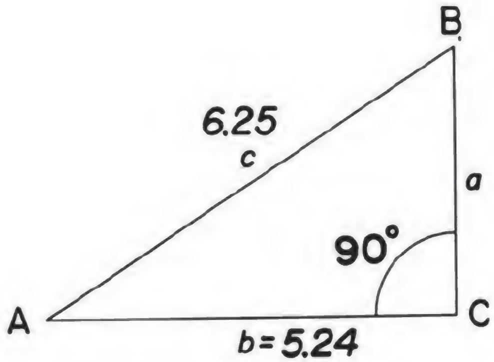
opposite the known side on D set opposite angle on S,
opposite any known side on D read opposite angle on S,
opposite any known angle on S read opposite side on D.

EXERCISES

Solve the following right triangles for the unknown values of A, B, a, b, and c.

(19) a = 50, A = 65°.	(22) A = 71°, b = 328.
(20) a = 21.2, B = 31.2°.	(23) c = 21.8, A = 47.3°.
(21) c = 200, A = 62°.	(24) b = 36.9, A = 12.35°.

For angles less than 5.73°, use the SRT scale for the sine of the angle.



1.378

Figure V-3.—Right triangle.

THE T (TANGENT) SCALE

The black numbers on the T scale represent angles from 5.71° to 45°, and the red numbers represent angles from 45° to 84.29°.

When the hairline is set to an angle A on T (black), tan A is at the hairline on C, and hence on scale D when the rule is closed. When the hairline is set to an angle A on T red, tan A is at the hairline on the CI scale.

The black legend indicates 0.1 to 1.0 or 5.71° to 45°, and the red legend indicated 1.0 to 10.0 or 45° to 84.29°

Example:
opposite 30° on T (black), read on C, 0.577 = tan 30°,
opposite 60° on T red, read on CI, 1.732 = tan 60°.

The cotangent of an angle may be found by using the formulas;

$$\cot A = \frac{1}{\tan A}, \text{ or } \cot A = \tan (90° - A).$$

Thus, to express the cotangent as the tangent of an angle, the following example is given.

cot 26° = tan (90° - 26°) = tan 64° and opposite 64° on T red read on CI, 2.05 = cot 26°, or

$$\cot 26° = \frac{1}{\tan 26°} \text{ and}$$

opposite 26° on T read on CI, 2.05 = cot 26°.

In computing an expression involving the tangent of an angle greater than 45° or any cotangent of an angle, it is advisable before beginning the computation to replace the tangent or cotangent by a tangent of an angle less than 45°. Thus to compute 428 tan 54°/cot 44° first write;

$$\frac{428 \tan 54°}{\cot 44°} = \frac{428 \cot 36°}{\cot 44°} = \frac{428 \tan 44°}{\tan 36°}$$

and then push the hairline to 428 on D, draw 36° of T under the hairline, push the hairline to 44° on T, at the hairline read on D, 568. The decimal point was placed after making the rough approximation of $\frac{400 \times 1}{0.7} = 550+$. The numbers 1 and 0.7 lie within the range of the T scale, 0.1 to 1.0 specified by the legend.

EXERCISES

(25) $\tan x = \frac{4.2}{5.6}$.

(26) $\tan x = \frac{3.9}{33}$.

(27) $\tan x = \frac{296}{428}$.

(28) $\tan x = \frac{529}{343}$.

(29) $\tan x = \frac{39.7}{86.3}$.

(30) $\tan x = \frac{1062}{2405}$.

(31) $\cot x = \frac{4}{5}$.

(32) $\cot x = \frac{16.3}{13.7}$.

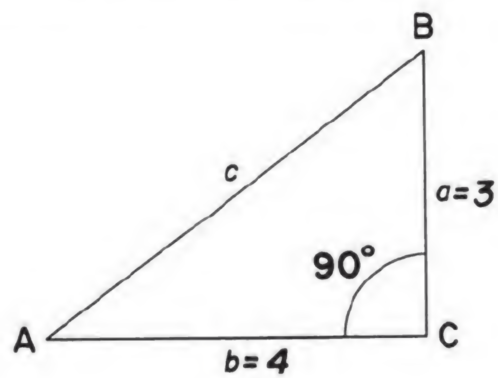
(33) $\cot x = \frac{211}{434}$.

THE LAW OF SINES APPLIED TO RIGHT TRIANGLES WITH TWO LEGS GIVEN

When the two legs of a right triangle are given, first find the smaller acute angle from its tangent and then apply the law of sines to complete the solution.

Example. Solve the triangle illustrated in figure V-4 in which a = 3 and b = 4.

Solution. From the triangle read $A = \tan \frac{3}{4}$.



1.379

Figure V-4.—Right triangle with two legs given.

Hence write $\frac{T}{D}: \frac{\tan A}{3} = \frac{1}{4}$ and

opposite 4 on D set index of C,
push hairline to 3 on D,
at hairline read A = 36.88° on T,
at hairline read B = 53.12 on T red. See figure V-5A.

Now complete the solution by using the method of sines as explained earlier. Since the hairline is set to 3 on D, draw the opposite angle 36.88° of S under the hairline, and opposite 1 (= sin 90°) on S read c = 5 on D. See figure V-5B.

Rule

To solve a right triangle for which two legs are given, to the larger leg on scale D set the proper index of the slide, push the hairline to the smaller leg on D, at the hairline read smaller acute angle of triangle on T, draw this angle on S under the hairline, and at the index of the slide read the hypotenuse on D.

Example. Solve the triangle illustrated in figure V-6 in accordance with the above rule.

Solution. Set the right index of C to 734 on D, push hairline to 396 on D,

at hairline read B = 28.4° on T,
draw 28.4° on S under the hairline,
at index of S read c = 833 on D.

Therefore A = 90° - B = 61.6°.

Exercises

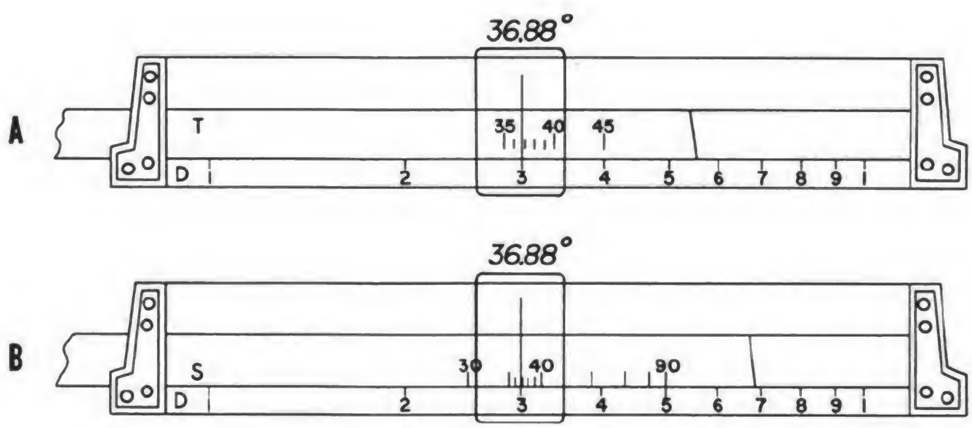
Solve the following right triangles for the unknown values of A, B, and c.

(34) a = 13.1, b = 16.9.
(35) a = 22, b = 31.
(36) a = 571, b = 627.
(37) a = 43.9, b = 80.1.
(38) a = 46, b = 43.1.
(39) a = 1034, b = 1678.

For a more detailed discussion on the use of the slide rule, refer to any authoritive slide rule manual such as those published by the Keuffel and Esser Co.

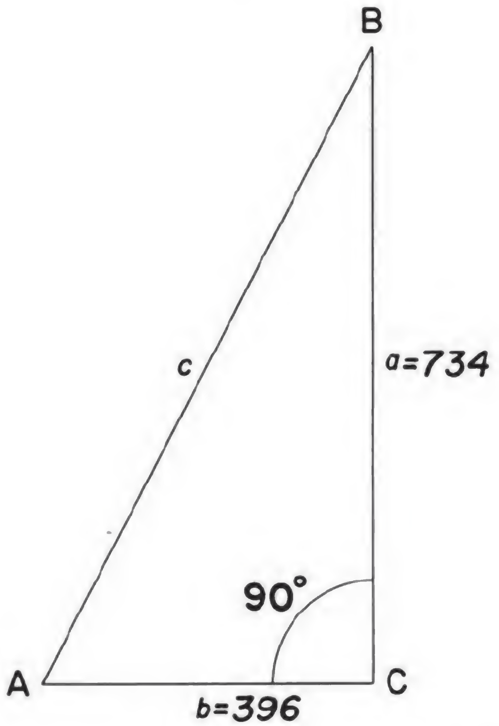
NOTE: ALL ANSWERS TO PROBLEMS SHOULD BE WITHIN 3 PLACES OF THE 3RD SIGNIFICANT FIGURE. ALL ANSWERS LISTED ARE TO TABLE ACCURACY.

	sin	cos
1.	0.5299	.8480
2.	0.8988	.4384
3.	0.0324	.9995
4.	0.0490	.9988
5.	0.7455	.6665
6.	0.9511	.3090
7.	0.0583	.9983
8.	0.8320	.5548
9.	0.0839	.9965
10.	1.0000	0.0000



1.380

Figure V-5. —Trigonometric scales of the slide rule. A. T scale. B. S scale.



1.381
Figure V-6. —Right triangle with two legs given.

	sin	cos
11.	0.9979	.0645
12.	0.7071	.7071

	sin x	cos x
13.	30°	60°
14.	42.9°	47.1°
15.	29°	61°
16.	5.73°	84.27°
17.	0.916°	89.084°
18.	2.1°	87.9°

19. b = 23.3
    c = 55.2
    B = 25°
20. b = 12.82
    c = 24.8
    A = 58.8°
21. a = 176.5
    b = 94
    B = 28°
22. a = 952
    c = 1006
    B = 19°
23. a = 16
    b = 14.77
    B = 42.7°
24. a = 8.08
    c = 37.8
    B = 77.65°
25. 36.9°
26. 6.74°
27. 34.64°
28. 57.05°
29. 24.7°
30. 23.7°
31. 51.4°
32. 40.25°
33. 64.1°
34. A = 37.6°
    B = 52.4°
    c = 21.4
35. A = 35.4°
    B = 54.6°
    c = 38
36. A = 42.35°
    B = 47.65°
    c = 849
37. A = 26.2°
    B = 63.8°
    c = 99.4
38. A = 46.9°
    B = 43.1°
    c = 63
39. A = 31.7°
    B = 58.3°
    c = 1970

APPENDIX VI

ELECTRONICS AND ELECTRICAL TERMS

AGONIC.—An imaginary line of the earth's surface passing through points where the magnetic declination is 0°; that is, points where the compass points to true north.

AMMETER.—An instrument for measuring the amount of electron flow in amperes.

AMPERE.—The basic unit of electrical current.

AMPERE-TURN.—The magnetizing force produced by a current of one ampere flowing through a coil of one turn.

AMPLIFICATION.—The process of increasing the strength (current, power, or voltage) of a signal.

AMPLIFICATION FACTOR (μ).—The ratio of a small change in plate voltage to a small change in grid voltage, with all other electrode voltages constant, required to produce the same small change in plate current.

AMPLIFIER.—A device used to increase the signal voltage, current, or power, generally composed of a vacuum tube and associated circuit called a stage. It may contain several stages in order to obtain a desired gain.

AMPLITUDE.—The maximum instantaneous value of an alternating voltage or current, measured in either the positive or negative direction.

ANODE.—A positive electrode; the plate of a vacuum tube.

ANTENNA.—A device used to radiate or receive radio waves.

AQUADAG.—A graphite coating on the inside of certain cathode-ray tubes for collecting secondary electrons emitted by the screen.

ARC.—A flash caused by an electric current ionizing a gas or vapor.

ARMATURE.—The rotating part of a d-c electric motor or generator. The moving part of a relay or vibrator.

ATMOSPHERE.—The whole mass of air surrounding the earth, including the troposphere, stratosphere, and the ionosphere.

ATTENUATION.—The reduction in the strength of a signal.

AUTOTRANSFORMER.—A transformer in which the primary and secondary are connected together in one winding.

AZIMUTH.—The angular measurement in a horizontal plane and in a clockwise direction, beginning at a point oriented to north.

BATTERY.—Two or more primary or secondary cells connected together electrically. The term does not apply to a single-cell.

BIAS.—Vacuum tube—the difference of potential between the contro grid and the cathode; transistor—the difference of potential between the base and emitter and the base and collector; magnetic amplifier—the level of flux density in the magnetic amplifier core—under no-signal condition.

BIAS WINDING.—The winding on the core of a magnetic amplifier that controls the bias.

BREAKER POINTS.—Metal contacts that open and close a circuit at timed intervals.

BRUSH.—The conducting material, usually a block of carbon, bearing against the commutator or sliprings through which the current flows in or out.

BUS BAR.—A primary power distribution point connected to the main power source.

CAPACITOR.—Two electrodes or sets of electrodes in the form of plates, separated from each other by an insulating material called the dielectric.

CATHODE.—The electrode in a vacuum tube which is the source of electron emission; also a negative electrode.

CHOKE COIL.—A coil of low ohmic resistance and high impedance to alternating current.

CIRCUIT.—The complete path of an electric current.

CIRCUIT BREAKER.—An electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a

predetermined amount. Circuit breakers can be reset.

CIRCULAR MIL.—An area equal to that of a circle with a diameter of 0.001 inch. It is used for measuring the cross section of wires.

COAXIAL CABLE.—A transmission line consisting of two conductors concentric with and insulated from each other.

COMMUTATOR.—The copper segments on the armature of a d-c motor or generator. It is cylindrical in shape and is used to pass power into or from the brushes. It is a switching device.

CONDUCTANCE.—The ability of a material to conduct or carry an electric current. It is the reciprocal of the resistance of the material, and is expressed in ohms.

CONDUCTIVITY.—A measure of the ability of a material to act as a path for electron flow. It is the opposite of resistivity and is expressed in mhos per meter.

CONDUCTOR.—Any material suitable for carrying electric current.

CORE.—A magnetic material that affords an easy path for magnetic flux lines in a coil.

COULOMB.—A unit of electrical charge; the quantity of electrical charge created by a steady flow of one ampere for one second.

COUNTER E.M.F.—Counter electromotive force; an e.m.f. induced in a coil or armature that opposes the applied voltage.

COUNTING CIRCUIT.—A circuit which receives uniform pulses representing units to be counted and produces a voltage in proportion to the frequency.

CRITICAL FREQUENCY.—The limiting frequency below which an electromagnetic wave is refracted back to earth by, and above which it penetrates through, an ionospheric layer at vertical incidence (straight up).

CURRENT LIMITER.—A protective device similar to a fuse, usually used in high amperage circuits.

CYCLE.—One complete positive and one complete negative alternation of a current or voltage.

DECIBEL (DB).—A term meaning one-tenth of a bel. The ratio of a change in power after attenuation or amplification.

DETECTION.—The process of separating the modulation component from the received signal.

DIELECTRIC.—An insulator; a term that refers to the insulating material between the plates of a capacitor.

DIFFRACTION.—The bending of a radio wave into the region behind an obstacle.

DIODE.—Vacuum tube—a two element tube that contains a cathode and plate; semiconductor—a material of either germanium or silicon that is manufactured to allow current to flow in only one direction. Diodes are used as rectifiers and detectors.

DIRECT WAVE.—A radio wave that is propagated directly through space from transmitter to receiving antenna.

DISTORTION.—The production of an output waveform which is not a true reproduction of the input waveform. Distortion may consist of irregularities in amplitude, frequency, or phase.

EDDY CURRENT.—Induced circulating currents in a conducting material that are caused by a varying magnetic field.

EFFICIENCY.—The ratio of output power to input power, generally expressed as a percentage.

ELECTRICITY.—The science which treats of the phenomena and laws of things electrical.

ELECTRODE.—A terminal used to emit, collect, or control electrons and ions; a terminal at which electric current passes from one medium into another.

ELECTROLYTE.—A solution of a substance which is capable of conducting electricity. An electrolyte may be in the form of either a liquid or a paste.

ELECTROMAGNET.—A magnet made by passing current through a coil of wire wound on a soft iron core.

ELECTROMOTIVE FORCE (E.M.F.).—The force that produces an electric current in a circuit.

ELECTRON.—A negatively charged particle of matter.

ELECTRON EMISSION.—The liberation of electrons from a body into space under the influence of heat, light, impact, chemical disintegration, or potential difference.

ELECTRONIC SWITCH.—A circuit which causes a start-and-stop action or a switching action by electronic means.

ENERGY.—The ability or capacity to do work.

EQUIVALENT CIRCUIT.—A diagrammatic arrangement of coils, resistors, and capacitors, representing the effects of a more

complicated circuit in order to permit easier analysis.

FARAD.—The unit of capacitance.

FEEDBACK.—A transfer of energy from the output circuit of a device back to its input.

FIELD.—The space containing electric or magnetic lines of force.

FIELD WINDING.—The coil used to provide the magnetizing force in motors and generators.

FILTERS.—A combination of circuit elements designed to pass a definite range of frequencies, attenuating all others.

FLUORESCENCE.—The property of emitting light as the immediate result of electronic bombardment.

FLUX FIELD.—All electric or magnetic lines of force in a given region.

FREE ELECTRONS.—Electrons which are loosely held and consequencly tend to move at random among the atoms of the material.

FREQUENCY.—The number of complete cycles per second existing in any form of wave motion; such as the number of cycles per second of an alternating current.

FREQUENCY OF OPTIMUM TRAFFIC (FOT).—The most reliable frequency at a specified time for ionospheric propagation of a radio wave between two specified points.

FULL-WAVE RECTIFIER CIRCUIT.—A circuit which utilizes both the positive and the negative alternations of an alternating current to produce a direct current.

FUSE.—A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

GAIN.—The ration of the output power, voltage, or current to the input power, voltage, or current, respectively.

GALVANOMETER.—An instrument used to measure small d-c currents.

GAS TUBE.—A tube that gives certain electrical characteristics because it is filled with a certain type of gas.

GATING (CATHODE-RAY TUBE).—Applying a rectangular voltage to the grid or cathode of a CRT to sensitize it during the sweep time only.

GENERATOR.—A machine that converts mechanical energy into electrical energy.

GRID.—A wire, usually in the form of a spiral, that controls the electron flow in a vacuum tube.

GRID DETECTION.—Detection by rectification in the grid circuit of a detector.

GRID LEAK.—A high resistance connected across the grid capacitor or between the grid and the cathode to provide a d-c path from grid to cathode and to limit the accumulation of charge on the grid.

GROUND.—A metallic connection with the earth to establish ground potential. Also, a common return to a point of zero potential. The chassis of a receiver or a transmitter is sometimes the common return, and therefore the "ground" of the unit.

GROUND WAVE.—A radio wave that travels close to the earth and reaches the receiving point without being refracted or acted upon by the ionosphere. The ground wave includes all components of a radio wave traveling over the earth except the sky (ionospheric) wave.

HARMONIC.—An integral multiple of a fundamental frequency. (The second harmonic is twice the frequency of the fundamental or first harmonic.)

HENRY.—The basic unit of inductance.

HETERODYNE.—To beat or mix two signals of different frequencies.

HOLE.—In semiconductors, the space in an atom left vacant by a departed electron. Holes flow in a direction opposite to that of electrons, are considered to be current carriers, and bear a positive charge.

HORSEPOWER.—The English unit of power, equal to work done at the rate of 550 foot-pounds per second. Equal to 746 watts of electrical power.

HYSTERESIS.—A lagging of the magnetic flux in a magnetic material behind the magnetizing force which is producing it.

IMPEDANCE.—The total opposition offered to the flow of an alternating current. It may consist of any combination of resistance, inductive reactance, and capacitive reactance.

INCIDENT WAVE.—A term denoting that portion of a radio wave which is about to strike a medium of different propagation characteristic which will result in that wave being refracted, reflected, diffracted, or scattered.

INDUCTANCE.–The property of a circuit which tends to oppose a change in the existing current.

INDUCTION.–The act or process of producing voltage by the relative motion of a magnetic field across a conductor.

INDUCTIVE REACTANCE.–The opposition to the flow of alternating or pulsating current caused by the inductance of a circuit. It is measured in ohms.

INDUCTOR.–A circuit element designed so that its inductance is its most important electrical property; a coil.

IN PHASE.–Applied to the condition that exists when two waves of the same frequency pass through their maximum and minimum values of like polarity at the same instant.

INTENSITY MODULATION.–The control of the brilliance of the trace on the screen of a cathode-ray tube in conformity with the signal.

INVERSELY.–Inverted or reversed in position or relationship.

IONOSPHERE.–The part of the earth's outer atmosphere where ions and electrons are present in quantities sufficient to affect the propagation of radio waves. The portion of the atmosphere above the stratosphere.

ISOGONIC LINE.–An imaginary line drawn through points on the earth's surface where the magnetic deviation is equal.

ISOTROPIC ANTENNA (UNIPOLE).–A hypothetical antenna equally radiating or receiving energy in all directions.

JOULE.–A unit of energy or work. A joule of energy is liberated by one ampere flowing for one second through a resistance of one ohm.

KLYSTRON.–A tube in which oscillations are generated by the bunching of electrons (that is, velocity modulation). This tube utilizes the transit time between two given electrodes to deliver pulsating energy to a cavity resonator in order to sustain oscillations within the cavity.

LAG.–The amount one wave is behind another in time; expressed in electrical degrees.

LAMINATED CORE.–A core built up from thin sheets of metal and used in transformers and relays.

LEAD.–The opposite of LAG. Also, a wire or connection.

LINEAR.–Having an output which varies in direct proportion to the input.

LINE OF FORCE.–A line in an electric or magnetic field that shows the direction of the force.

LOAD.–The power that is being delivered by any power producing device. The equipment that uses the power from the power producing device.

LOWEST USABLE FREQUENCY (LUF).–The LUF, based on the signal-to-noise ratio, varies as the power or the bandwidth is varied. An increase in power or a decrease in bandwidth will lower LUF, and a decrease in power or an increase in bandwidth will raise the LUF. A small change in power will not materially effect the LUF.

MAGNETIC AMPLIFIER.–A saturable reactor type device that is used in a circuit to amplify or control.

MAGNETIC CIRCUIT.–The complete path of magnetic lines of force.

MAGNETIC FIELD.–The space in which a magnetic force exists.

MAGNETIC FLUX.–The total number of lines of force issuing from a pole of a magnet.

MAGNETIZE.–To convert a material into a magnet by causing the molecules to rearrange.

MAGNETO.–A generator which produces alternating current and has a permanent magnet as its field.

MAGNETOSTRICTION.–A change in physical size of a magnetic material produced by the effect of a magnetic field.

MAGNETRON.–A vacuum-tube oscillator containing two electrodes, in which the flow of electrons from cathode to anode is controlled by an externally applied magnetic field.

MAXIMUM USABLE FREQUENCY (MUF).–The upper limit of the frequencies which can be used at a specified time for radio transmission between two points involving propagation by refraction from the regular ionized layers of the ionosphere. (Frequencies higher than the MUF may be transmitted by sporatic and scattered reflections.)

MEGGER.–A test instrument used to measure insulation resistance and other high resistances. It is a portable hand-operator d-c generator used as an ohmmeter.

MEGOHM.–A million ohms.

MICRO.–A prefix meaning one-millionth.

MILLI.—A prefix meaning one-thousandth.

MILLIAMMETER.—An ammeter that measures current in thousandths of an ampere.

MODULATION.—The process of varying the amplitude (amplitude modulation), the frequency (frequency modulation), or the phase (phase modulation) of a carrier wave in accordance with other signals in order to convey intelligence. The modulating signal may be an audiofrequency signal, video signal (as in television), or electrical pulses or tones to operate relays, etc.

MOTOR-GENERATOR.—A motor and a generator with a common shaft used to convert line voltages to other voltages or frequencies.

MUTUAL INDUCTANCE.—A circuit property existing when the relative position of two inductors causes the magnetic lines of force from one to link with the turns of the other.

NEGATIVE CHARGE.—The electrical charge carried by a body which has an excess of electrons.

NEUTRONS.—A particle having the weight of a proton but carrying no electric charge. It is located in the nucleus of an atom.

NIXIE.—An electronic solid state device which displays letters or numerals on its luminous surface.

NOISE.—Any extraneous electrical disturbance tending to interfere with the normal reception of a transmitted signal.

NONLINEAR.—Having an output which does not vary in direct proportion to the input.

NUCLEUS.—The central part of an atom that is mainly comprised of protons and neutrons. It is the part of the atom that has the most mass.

NULL.—Zero.

OHM.—The unit of electrical resistance.

OHMMETER.—An instrument for directly measuring resistance in ohms.

OSCILLOSCOPE.—An instrument for showing, visually, graphical representations of the waveforms encountered in electrical circuits.

OVERLOAD.—A load greater than the rated load of an electrical device.

PERMALLOY.—An alloy of nickel and iron having an abnormally high magnetic permeability.

PERMEABILITY.—A measure of the ease with which magnetic lines of force can flow through a material as compared to air.

PHASE DIFFERENCE.—The time in electrical degrees by which one wave leads or lags another.

PHOSPHORESCENCE.—The property of emitting light for some time after excitation by electronic bombardment.

PLATE.—The principal electrode in a tube to which the electron stream is attracted.

PLATE CURRENT.—The current flowing in the plate circuit of a vacuum tube.

PLATE DETECTION.—The operation of a vacuum-tube detector at or near cutoff so that the input signal is rectified in the plate circuit.

PLATE RESISTANCE (r_ρ).—The internal resistance to the flow of alternating current between the cathode and plate of a tube. It is equal to a small change in plate voltage divided by the corresponding change in plate current, and is expressed in ohms. It is also called a-c resistance, internal impedance, plate impedance, and dynamic plate impedance. The static plate resistance, or resistance to the flow of direct current, is a different value. It is denoted by r_ρ.

POLARITY.—The character of having magnetic poles, or electric charges.

POLE.—The section of a magnet where the flux lines are concentrated; also where they enter and leave the magnet. An electrode of a battery.

POLYPHASE.—A circuit that utilizes more than one phase of alternating current.

POSITIVE CHARGE.—The electrical charge carried by a body which has become deficient in electrons.

POTENTIAL.—The amount of charge held by a body as compared to another point or body. Usually measured in volts.

POTENTIOMETER.—A variable voltage divider; a resistor which has a variable contact arm so that any portion of the potential applied between its ends may be selected.

POWER.—The rate of doing work or the rate of expanding energy. The unit of electrical power is the watt.

POWER FACTOR.—The ratio of the actual power of an alternating or pulsating current, as measured by a wattmeter, to the apparent power, as indicated by ammeter and voltmeter readings. The power factor of an

inductor, capacitor, or insulator is an expression of their losses.

PRIME MOVER.–The source of mechanical power used to drive the rotor of a generator.

PROTON.–A positively charged particle in the nucleus of an atom.

PUSH-PULL CIRCUIT.–A push-pull circuit usually refers to an amplifier circuit using two vacuum tubes in such a fashion that when one vacuum tube is operating on a positive alternation, the other vacuum tube operates on a negative alternation.

RATIO.–The value obtained by dividing one number by another, indicating their relative proportions.

REACTANCE.–The opposition offered to the flow of an alternating current by the inductance, capacitance, or both, in any circuit.

RECIPROCAL.–The value obtained by dividing the number 1 by any quantity.

RECTIFIERS.–Devices used to change alternating current to unidirectional current. These may be vacuum tubes, semiconductors such as germanium and silicon, dry-disk rectifiers such as selenium and copper-oxide, and also certain types of crystal.

REFLECTION.–The phenomenon which, when a radio wave strikes a medium of different propagation characteristics (such as the earth or ionosphere), causes the wave to be returned into the original medium (ionosphere or the earth) with the angles of incidence and of reflection equal and lying in the same plane.

REFRACTION.–The phenomenon which, when a radio wave or other radiation passes from one medium (such as the stratosphere) to another medium (such as the ionosphere), causes the wave to bend. The angles of incidence and of reflection are not equal or necessarily lying in the same plane.

RELAXATION OSCILLATOR.–A circuit for the generation of nonsinusoidal waves by gradually storing and quickly releasing energy either in the electric field of a capacitor or in the magnetic field of an inductor.

RELAY.–An electromechanical switching device that can be used as a remote control.

RELUCTANCE.–A measure of the opposition that a material offers to magnetic lines of force.

RESISTANCE.–The opposition to the flow of current caused by the nature and physical dimensions of a conductor.

RESISTOR.–A circuit element whose chief characteristic is resistance; used to oppose the flow of current.

RESONANCE.–The condition existing in a circuit in which the inductive and capacitive reactances cancel each other.

RESONANCE CURVE.–A graphical representation of the manner in which a resonant circuit responds to various frequencies at and near the resonant frequency.

RETENTIVITY.–The measure of the ability of a material to hold its magnetism.

RHEOSTAT.–A variable resistor.

SATURABLE REACTOR.–A control device that uses a small d-c current to control a large a-c current by controlling core flux density.

SATURATION.–The condition existing in any circuit when an increase in the driving signal produces no further change in the resultant effect.

SELF-INDUCTION.–The process by which a circuit induces an e.m.f. into itself by its own magnetic field.

SERIES-WOUND.–A motor or generator in which the armature is wired in series with the field winding.

SERVO.–A device used to convert a small movement into one of greater movement or force.

SERVOMECHANISM.–A closed-loop system that produces a force to position an object in accordance with the information that originates at the input.

SKY WAVE.–A radio wave that is propagated or acted upon by the ionosphere.

SOLENOID.–An electromagnetic coil that contains a movable plunger.

SPACE CHARGE.–The cloud of electrons existing in the space between the cathode and plate in a vacuum tube, formed by the electrons emitted from the cathode in excess of those immediately attracted to the plate.

SPACE WAVE.–Often called the tropospheric wave. A radio wave that travels entirely through the earth's troposphere.

STANDING WAVE.–A distribution of current and voltage on a transmission line formed by two sets of waves traveling in opposite directions, and characterized by the presence of a number of points

of successive maxima and minima in the distribution curves.

STATIC.—A fixed nonvarying condition; without motion.

STRATOSPHERE.— The part of the earth's atmosphere between the troposphere and the ionosphere.

SUNSPOT NUMBERS.—The number of dark irregularly shaped areas on the surface of the sun caused by violent solar eruptions. The spots are counted and then averaged over a period of time to obtain values which are expressed as "smooth sunspot numbers." These smooth sunspot numbers are used to predict the average sunspot activity over a period of time.

SURFACE WAVE.—A radio wave that travels in contact with the surface of the earth.

SWEEP CIRCUIT.—The part of a cathode-ray oscilloscope which provides a time-reference base.

SYNCHRO SYSTEM.—An electrical system that gives remote indications or control by means of self-synchronizing motors.

SYNCHRONOUS.—Happening at the same time; having the same period and phase.

TACHOMETER.—An instrument for indicating revolutions per minute.

TERTIARY WINDING.—A third winding on a transformer or magnetic amplifier that is used as a second control winding.

THERMISTOR.—A resistor that is used to compensate for temperature variations in a circuit.

THERMOCOUPLE.—A junction of two dissimilar metals that produces a voltage when heated.

TRACE.—A visible line or lines appearing on the screen of a cathode-ray tube in operation.

TRANSFORMER.—A device composed of two or more coils, linked by magnetic lines of force, used to transfer energy from one circuit to another.

TRANSMISSION LINES.—Any conductor or system of conductors used to carry electrical energy from its source to a load.

TRIGGERING.—Starting an action in another circuit, which then functions for a time under its own control.

TRIODE.—A three-electrode vacuum tube, containing a cathode, control grid, and plate.

TROPOSPHERE.—The lowest part of the earth's atmosphere. In this region, which extends from the surface of the earth to the stratosphere, temperature decreases with altitude, clouds form, and all weather phenomena take place.

TUNED CIRCUIT.—A resonant circuit.

VACUUM TUBE.—An evacuated envelope containing two or more electrodes.

VECTOR.—A line used to represent both direction and magnitude.

VIDEO AMPLIFIER.—A circuit capable of amplifying a very wide range of frequencies, including and exceeding the audio band of frequencies.

VOLT.—The unit of electrical potential.

WATT.—The unit of electrical power.

WATTMETER.—An instrument for measuring electric power in watts.

WAVEFORM.—The shape of the wave obtained when instantaneous values of an a-c quantity are plotted against time in rectangular coordinates.

WAVELENGTH (λ).—The distance, usually expressed in meters, traveled by a wave during the time interval of one complete cycle. It is equal to the velocity divided by the frequency.

INDEX